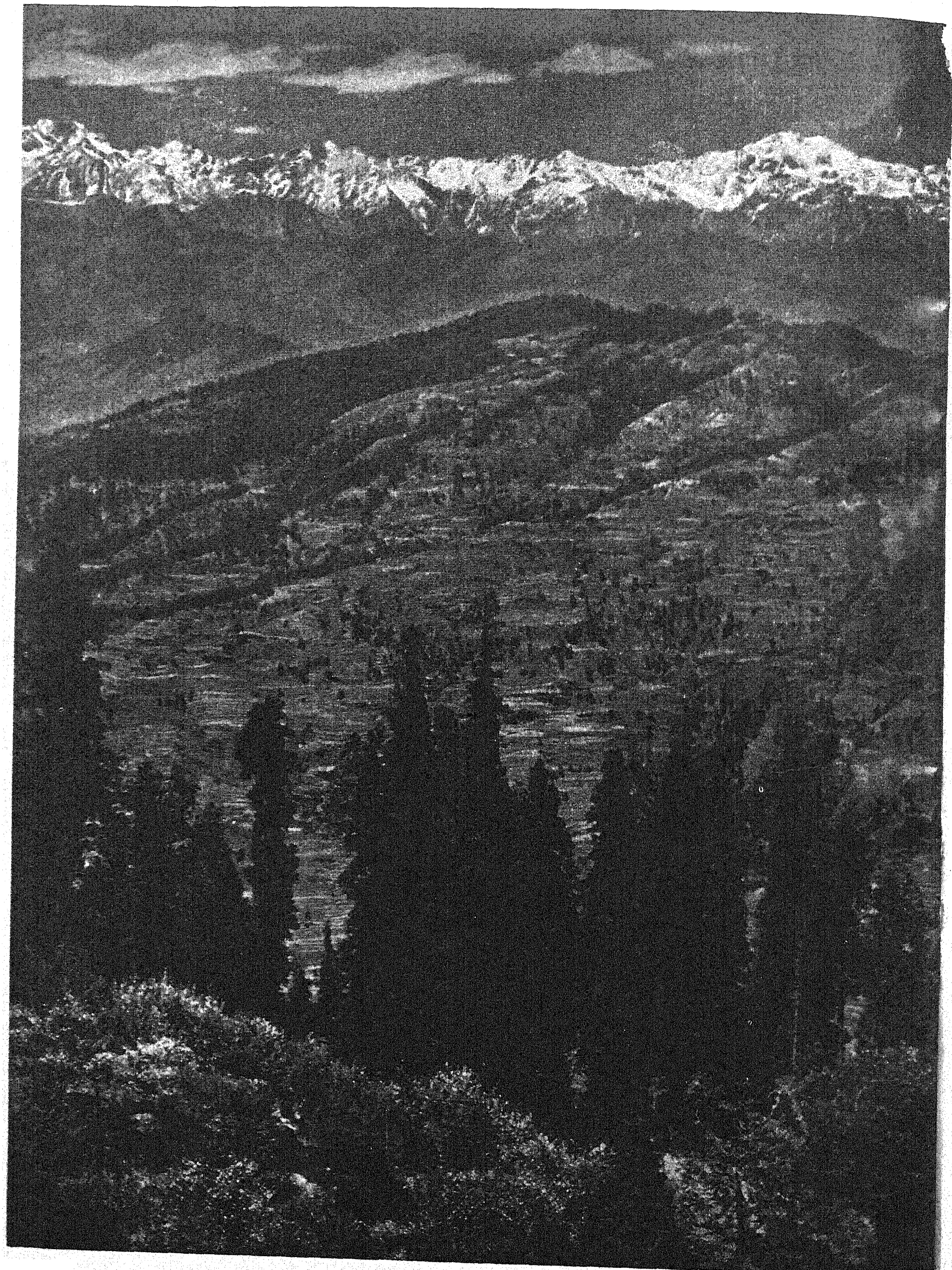
WHEAT



Wheat terraces, against a backdrop of perpetual snow, in Himachal Pradesh

WHEAT

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FOREWORD

Wheat is a cereal where our deficit is maximum. In recent years wheat has become popular even in traditionally rice-eating areas. The demand has, therefore, grown and our major external supply source has been the United States. As in the other food crops, the average yield of wheat in our country is very low and our annual production now is of the order of ten million tonnes from an area of nearly 15 million hectares. The low yields are the result of a variety of reasons; but it is clear that many of the older wheat strains cultivated in our country have been selected more for resistance to drought and adverse conditions than for efficient performance under conditions of good irrigation and adequate soil nutrition. In fact, the wheat kernel identified in the Mohenjo-Daro excavations belong to a species which is exceedingly drought-resistant. If we are to grow more food on the existing land, the per-hectare productivity of our crops has to be greatly increased. This can be done only through the collaborative efforts of a team of scientists belonging to different disciplines, all striving to produce a plant with an integrated personality—by which I mean, the ability of the variety to live in harmony with its environment and to use most effectively sunlight, water and nutrients. It would be futile to expect that any one input alone would help us to make a substantial gain in yield. For example, when a variety which is susceptible to rusts is grown with fertilizers, the increased incidence of diseases more than offsets the improvement in yield potential caused by the fertilizer. It is therefore necessary that the problem is viewed as a whole and all the forces made to interact in a manner that would help us to achieve the desired end-result.

This excellent book which contains the results of over thirty years of devoted work on the wheat crop by Dr. B. P. Pal, has appeared at a most appropriate time. Recent developments in wheat breeding resulting in the evolution of dwarf and fertilizer-responsive strains have opened new vistas in stepping up the production of this crop. An All-India Coordinated Wheat Improvement Project has been initiated and with the deployment of more financial resources, more skilled research workers would also be needed. Students and research and extension workers would find in this book a wealth of material on all aspects of the wheat plant and its cultivation. I hope that the example set by Dr. Pal would stimulate the compilation of such books on all our major agricultural crops and problems. All those interested in Indian agriculture would be grateful to Dr. Pal and to the Indian Council of Agricultural Research for bringing out such a valuable compilation at a time when it will be of great practical utility.

New Delhi
December 26, 1966

C. Subramaniam
Minister for Food and Agriculture

PREFACE

Since the publication of ' Wheat in India ' by the Howards, a great deal of work has been done in this country on various aspects of wheat. In particular, the breeding work has been very noteworthy resulting in the production of new strains combining high yield, excellent grain quality and considerable resistance to the rust and smut diseases. It was with pleasure, therefore, that I accepted the invitation of the Indian Council of Agricultural Research to prepare a book on wheat, though I realized the task was a difficult one. The general principle followed has been to give as complete an account as possible on a world-wide basis of such subjects as Cytogenetics and Physiology, because fundamental advances in these disciplines are of interest to wheat workers, no matter in which country they are working. In the case, however, of subjects like Agronomy and Marketing, the treatment has been mainly in respect of this country. In the short period of time which was available, it has scarcely been possible for me to do full justice to the subject but I hope that whatever has been done will prove of some interest and value to those engaged on the improvement of wheat production or the processing or other activities pertaining to this most important commodity.

It would not have been possible for me to complete this work without very extensive and generous help of a large number of persons. In particular, I must mention the following for assistance received in drafting the chapters shown against their names :

Agronomy	P. C. Raheja, A. R. Khan, O. P. Gautam, R. D. Verma, Mukhtar Singh and K. S. Yawalkar
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Systematics and Morphology	S. Kedharnath
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Grain quality	N. B. Das
Marketing	T. P. S. Chowdhury
Physiology	R. D. Asana
Soils and Fertilizers	S. P. Raychaudhuri
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If I have omitted any names through oversight, I apologize for the same.

Finally, I must express my debt of gratitude to Dr. M. S. Randhawa, formerly Vice-President, Indian Council of Agricultural Research, for the encouragement and inspiration he gave me to take up this task.

Indian Agricultural Research Institute
New Delhi, December 21, 1961
B. P. PAL

Owing to the regrettable delay in the publication of this book some of the subject matter became out-of-date, but any attempt to do a complete revision would have entailed yet further delay. Therefore, an attempt has been made only to revise such portions as was feasible at this stage. However, a short but authoritative note summarizing some recent and important advances in the field of wheat research in India has been prepared by Dr. M. S. Swaminathan, Director, Indian Agricultural Research Institute, at my request. This is given at the end of the book.

As a result of the reorganization of the erstwhile State of Bombay into the states of Maharashtra and Gujarat there have been some consequential changes in the text of some of the chapters. It has also not been possible to employ uniformly the metric system of weights and measures.

Indian Council of Agricultural Research
New Delhi, November 8, 1966
B. P. PAL

CONTENTS

PAGE

FOREWORD vii

PREFACE ix

I. INTRODUCTION 1

II. ORIGIN AND HISTORY 14

III. SYSTEMATICS AND MORPHOLOGY 19
  Taxonomy and nomenclature 19
  Morphology 23
  Anatomy 25
  Embryology 29
  Classification 33
  Description of wheat species 34
  Classification of agricultural varieties 45

IV. CYTOGENETICS AND GENETICS 48
  Cytogenetical studies 48
  Genetical studies 57

V. CYTOGENETICS IN RELATION TO WHEAT BREEDING 74

VI. WHEAT BREEDING 86
  Wheat breeding in India 89
  Wheat-breeding problems and objectives 95
  Early wheat-breeding work 105
  Wheat breeding at the I.A.R.I. and the states 109

VII. IMPORTANT WHEAT VARIETIES OF INDIA 132
  Important improved varieties 132
  Description of selected improved varieties 141

VIII. GRAIN QUALITY 161
  Proteins in wheat 161
  Vitamins 167
  Sugars 170
  Fat 170
  Phytic acid 170
  Mineral matter 171
  Effect of milling 172
  Enzymes in flour 173
  Baking and *chapattee*-making quality 175
  Wheat blends and substitutes 178

PAGE

IX. PHYSIOLOGY 183
Moisture relations 183
Influence of light and temperature on wheat 191
Vernalization 194
Growth and nutrition 197
Lodging 203

X. DISEASES 208
Rusts 208
Smuts and bunts 224
Powdery mildew 232
Leaf blotch 235
Helminthosporium diseases 237
Other diseases 238

XI. PESTS 244

XII. SOILS IN RELATION TO WHEAT 251
Soils of wheat-growing areas 251

XIII. AGRONOMY—MANURES AND FERTILIZERS 258
Response to fertilizers 258
Micronutrients 278
Manures and fertilizers in relation to soils 278
Foliar application of fertilizers for increasing yield of wheat .. 280

XIV. AGRONOMY—CULTURAL PRACTICES 282
Wheat in rotation 294
Mixed cropping with wheat 298
Moisture requirements of wheat 302
Weeds and their control in wheat crop 312
Costs of cultivation 322

XV. WHEAT STRAW 327

XVI. IMPLEMENTS AND MACHINERY 328
Tillage operations with indigenous implements 328
Seed-bed preparation 333
Sowing 334
Intercultivation 335
Harvesting and threshing 341

XVII. MARKETING 344

ADDENDUM 354

GLOSSARY 357

INDEX 359

LIST OF PLATES

PAGE

Frontispiece. Wheat terraces, against a backdrop of perpetual snow, in Himachal Pradesh.

Plate 1. Terrace cultivation in the hills 11
2. Threshing of wheat in the hills 11
3. Campus of the Indian Agricultural Research Institute, New Delhi (an aerial view) 12
4. Diploid species of *Triticum* 17
5. Tetraploid species of *Triticum* 18
6. Hexaploid species of *Triticum* 21
7. Carbonized wheat grains from Mohenjo-Daro 21
8. *Triticum boeoticum* 22
9. *Triticum dicoccoides* 22
10. *Triticum dicoccum* 31
11. *Triticum durum* 32
12. *Triticum timopheevi* 41
13. *Triticum aestivum* 41
14. *Triticum sphaerococcum* 42
15. *Triticum macha* 42
16. Somatic chromosomes in *Triticum* and allied genera 51
17. Monosomic analysis—B_2 in chromosome X (6B) 52
18. Monosomic analysis—*Hd* in chromosome VIII (4B) 52
19. Monosomic analysis—*Q* in chromosome IX (5A) 55
20. PMC of a haploid N.P. 809 plant, showing 17 univalents and two bivalents. 55
21. Homoeologous groups in wheat and the characters located on each chromosome through monosomic analysis 56
22. A, Segregation for awning in F_2 of cross of Beardless × Fully bearded; B, One-factor segregation for awning in a cross between a reduced awn and fully awned varieties 61
23. 1. A, Ear of *Triticum vavilovi* (Simla grown); B, Ear of *T. vavilovi* (Delhi grown); C, Variation in extent of branching in the ears of the same plant of *T. vavilovi*. 2. Ears of the F_3 progeny of a true branching F_2 plant. A, Branched ear; B, Non-branched ear. 3. Various types of branching and extra glume derivates .. 62
24. Ear types in F_2 and F_3 of *T. vavilovi* × *T. sphaerococcum* .. 65
25. A tall wheat variety grown with 40 lb. N/acre showing lodging .. 66
26. S. 64, a two-gene dwarf developed in Mexico and found widely adapted in India 66

PAGE

Plate 27. Autoradiograph of wheat seedlings treated with P^{32} 75
28. Variability in ear characters induced by radiation (N.P. 809) .. 76
29. Mutations induced in N.P. 809 by P^{32} treatment 77
30. A range of short- and stiff-strawed mutants in C. 591 78
31. Short-strawed, dense-eared plants and long-strawed, lax-eared plants of N.P. 809 87
32. A beardless mutant in C. 591 88
33. Prof. H. Kihara and Prof. N. V. Tsitsin 91
34. Prof. E. R. Sears and Prof. H. K. Hayes 92
35. Sir Albert Howard and Mrs G. L. C. Howard 93
36. Dr. B. P. Pal and Dr. M. S. Swaminathan 94
37. Dr. S. M. Sikka and Dr. B. S. Kadam 97
38. Shri R. B. Ekbote and Chaudhary Ram Dhan Singh 98
39. General view of experimental fields of the Botany Division, Indian Agricultural Research Institute, New Delhi 103
40. N.P. 4 103
41. N.P. 12 104
42. N.P. 165 107
43. N.P. 710 108
44. N.P. 770 113
45. N.P. 790, one of the most valuable sources of stem rust resistance in India 114
46. N.P. 809 119
47. N.P. 823 120
48. N.P. 824 123
49. N.P. 829 124
50. Hybrid 65 124
51. N.P. 200 124
52. R.S. 31-1 127
53. C. 13 128
54. K. 54 128
55. Ears of N.P. 4, N.P. 52, N.P. 125, N.P. 165, N.P. 710 and N.P. 718 143
56. Ears of N.P. 761, N.P. 770, N.P. 797, N.P. 792, N.P. 798 and N.P. 799 144
57. Ears of N.P. 809, N.P. 823, N.P. 824, N.P. 829, N.P. 200 and Ridley 149
58. Ears of C. 217, C. 228, C. 591 and C. 518 150
59. Ears of C. 273, C. 281, C. 285, C. 286, Hy. 11 and Hy. 65 .. 153
60. Ears of Hy. 38, Hy. 277, *Jay*, *Vijay*, Niphad-4 and Kenphad 25 .. 154
61. Ears of N. 177 and N. 345 159
62. Ears of C. 13 and R.S. 31-1 160
63. Dr. K. C. Mehta 213
64. Interior of the rust glass-house. 213
65. Mycological substation of the Indian Agricultural Research Institute, Simla 214
66. Spraying rust inoculum in the field 217

PAGE

Plate 67. Maintaining humidity around infected plots 218
68. Rust inoculation at boot stage by injecting spore suspension .. 219
69. Culms of wheat attacked by black rust (*Puccinia graminis tritici*) .. 220
70. Wheat plants affected by loose smut (*Ustilago tritici*) .. 227
71. Inoculation of wheat ears with loose smut spores 228
72. Healthy grains of wheat compared with grains affected by hill bunt (*Tilletia foetida* and *T. caries*) and by Karnal bunt (*Neovossia indica*) 233
73. Plants affected by flag smut of wheat (*Urocystis tritici*) .. 233
74. Plants affected by powdery mildew of wheat (*Erysiphe graminis tritici*) 233
75. Wheat ears affected by Tundu (*Corynebacterium tritici*) 234
76. Levelling of green-manure crop of sunnhemp preparatory to burying in 285
77. Burying in of the green-manure crop 285
78. Discing before cultivation 286
79. Preparatory tillage with tractor 286
80. Final cultivation with *desi* plough 289
81. Dropping seed by local drill 290
82. Closer view of dropping seed by local drill 295
83. Planking the seed-bed after sowing 296
84. Bullock-drawn seed drill in operation 296
85. Sowing with tractor-drawn seed drill 299
86. Harvesting wheat (according to the traditional method) with sickles 300
87. Mechanized harvesting of wheat 300
88. Transportation of sheaves of wheat to the threshing floor .. 317
89. Wheat threshing 317
90. Winnowing 318
91. Wheat grain in bulk 319
92. Baking *chapattees* (unleavened bread) 320
93. Mould board plough 329
94. Float for smoothening and finer levelling of land 329
95. Blade harrows. *Bakhar* and *Guntaka* 330
96. Bund former 330
97. Buck scraper for land levelling 331
98. Wooden seed drill 331
99. Seed drill by which seed rate and depth of sowing can be adjusted 331
100. Three-tyne cultivator with seed spout attachment 332
101. Austrian scythe and toothed sickle 332
102. Animal-drawn reaper for harvesting and wind-rowing standing crop 337
103. Threshing with Olpad thresher 337
104. Threshing with *palla* 338
105. Winnowing machine 338
106. Ludhiana thresher 339
107. Fan for creation of breeze for winnowing 340

LIST OF FIGURES

PAGE

Figure 1. Distribution of wheat in India 9
2. Transverse section of a part of primary root of *Triticum aestivum* 26
3. Transverse section of stem of *Triticum aestivum* 27
4. Leaf epidermis. A, upper epidermis of W.R.S. (*T. aestivum*); B, upper epidermis of W.G. 12 (*T. aestivum*); C, different types of hairs occurring on the leaf epidermis of *Triticum* species 28
5. Leaf sheath epidermis of N.P. 114 (*T. aestivum*) 29
6. Transverse section of a part of leaf of *Triticum aestivum* 30
7. Development and differentiation of the wheat embryo 33
8. Structure of the wheat grain 173
9. Composition of various fractions separated during the milling process 174
10. Soil moisture status during the growth period of a wheat crop grown under rainfed conditions 190
11. Growth (increase of stem, leaf, ear and total plant dry weight in grams) and uptake of N, P and K in weekly samples 199
12. Grain development in wheat 202
13. Field pests of wheat. 1, 1a, *Odontotermes obesus* Ramb.; 2, 2a, *Microtermes obesi* (Anardi) H.; 3, *Aphis maidis* Fitch.; 4, *Toxoptera graminum* R.; 5, *Chrotogonus* spp.; 6, 6a, *Sesamia inferens* Wlk.; 7, *Anguina tritici* (Steinbuch) Chitwood 247
14. Storage pests of wheat. 1, *Sitophilus oryzae* L.; 2, *Rhizopertha dominica* Fab.; 3, 3a, *Trogoderma granarium* Everts; 4, 4a, *Tribolium castaneum* Herbst; 5, 5a, *Sitotroga cerealella* Olivier 248
15. Response of wheat to ammonium sulphate and ammonium nitrate at different levels of nitrogen 262
16. Response of wheat to farmyard manure (irrigated crop) 266
17. Yield of wheat to nitrogen and phosphorus applied in combination (irrigated crop) 274
18. Trends of wheat production and acreage in India 344
19. Share of major producing states in acreage and production of wheat 345
20. Wheat marketing channels in India 347
21. Sharing of the consumer's rupee 349
22. Average monthly indices of wholesale price of wheat, 1949-50—1956-57 350

CONVERSION TABLE

IMPERIAL TO METRIC SYSTEM

Linear Measures

Inches	×	2·54	=	Centimetres
Feet	×	0·305	=	Metres
Yards	×	0·914	=	Metres
Miles	×	1·609	=	Kilometres

Square Measures

Square inches	×	6·452	=	Square centimetres
Square feet	×	0·093	=	Square metres
Square yards	×	0·836	=	Square metres
Acres	×	0·405	=	Hectares
Square miles	×	2·590	=	Square kilometres

Cubic Measures

Cubic inches	×	16·387	=	Cubic centimetres
Cubic feet	×	0·028	=	Cubic metres
Cubic yards	×	0·765	=	Cubic metres

Weights

Grains	×	0·065	=	Grams
Avoirdupois ounces	×	28·350	=	Grams
Troy ounces	×	31·104	=	Grams
Avoirdupois pounds	×	0·454	=	Kilograms
Hundredweights	×	0·508	=	Quintals

Concentration

Ounces per Imperial gallon	×	6·236	=	Grams per litre
Ounces per U.S. gallon	×	7·490	=	Grams per litre

Yields

Pounds per acre	×	1·121	=	Kilograms per hectare
Pounds per acre	×	0·011	=	Quintals per hectare
Hundredweights per acre	×	125·54	=	Kilograms per hectare
Hundredweights per acre	×	1·255	=	Quintals per hectare
Gallons per acre	×	11·23	=	Litres per hectare

Example

6 Inches	=	6	×	2·54	=	15·24	Centimetres
3 Feet	=	3	×	0·305	=	0·915	Metres
50 Hundredweights	=	50	×	0·508	=	25·40	Quintals
100 Gallons per acre	=	100	×	11·23	=	1123	Litres per hectare

CONVERSION TABLE—(*Contd.*)

METRIC TO IMPERIAL SYSTEM

Linear Measures

Centimetres	×	0·394	=	Inches
Metres	×	3·281	=	Feet
Metres	×	1·094	=	Yards
Kilometres	×	0·621	=	Miles

Square Measures

Square centimetres	×	0·155	=	Square inches
Square metres	×	10·764	=	Square feet
Square metres	×	1·196	=	Square yards
Hectares	×	2·471	=	Acres
Square kilometres	×	0·386	=	Square miles

Cubic Measures

Cubic centimetres	×	0·061	=	Cubic inches
Cubic metres	×	35·315	=	Cubic feet
Cubic metres	×	1·308	=	Cubic yards

Weights

Grams	×	15·432	=	Grains
Grams	×	0·035	=	Avoirdupois ounces
Grams	×	0·032	=	Troy ounces
Kilograms	×	2·205	=	Avoirdupois pounds
Quintals	×	1·968	=	Hundredweights

Concentration

Grams per litre	×	0·160	=	Ounces per Imperial gallon
Grams per litre	×	0·134	=	Ounces per U.S. gallon

Yields

Kilograms per hectare	×	0·892	=	Pounds per acre
Quintals per hectare	×	89·218	=	Pounds per acre
Kilograms per hectare	×	0·008	=	Hundredweights per acre
Quintals per hectare	×	0·796	=	Hundredweights per acre
Litres per hectare	×	0·089	=	Gallons per acre

Example

25 Centimetres	=	25	×	0·394	=	9·85	Inches
1·5 Metres	=	1·5	×	3·281	=	4·922	Feet
50 Quintals	=	50	×	1·968	=	98·4	Hundredweights
1000 Litres per hectare	=	1000	×	0·089	=	89	Gallons per acre

I

INTRODUCTION

Bread, made from wheat, has been the staff of life for countless numbers of human beings, right from the dawn of history when man first turned from an arboreal or nomadic life to settled agriculture, based on the cultivation of plants and the domestication of animals. Wheat is usually accorded a premier place among cereals because of the vast acreage devoted to its cultivation, its high nutritive value and its association with some of the earliest and most important civilizations of the world. If rice is the staple food of half of the world, wheat is the chief sustenance of the other half. The total acreage under wheat in the world is about 428,000,000 acres, with an annual production of 174,000,000 tons.

While wheat is grown over a wide range of latitudes covering a considerable diversity of conditions, the largest quantities of the best wheats are produced in countries favoured with cool, moist weather during a fairly long growing period followed by dry, warm weather to enable the grain to ripen properly. Wheat cultivation is so widely distributed geographically that the crop is being harvested in one country or the other all the year round. Distribution of the acreage under wheat in the world, the respective production and also the yield per acre are given in Table I.

WHEAT IN INDIA

The north-western corner of the Indian sub-continent, between the Himalayan Range and the Hindu Kush Mountains, is regarded as the original home of the most important present-day cultivated species of wheat, i.e., *Triticum aestivum*, the bread wheat. Today, among the cereal crops grown in India, wheat comes next only to rice and sorghum from the point of intensity of cultivation. In 1956-57, wheat accounted for nearly 15 per cent of the area under cereals and 9 per cent of the area under all crops. The share of wheat in the gross sown area during this period was stated to be the highest in the Punjab (20·9 per cent), followed by Uttar Pradesh (18·9 per cent), Madhya Pradesh (19·4 per cent), Rajasthan (9·9 per cent), Bihar (7·5 per cent) and Bombay (5·2 per cent). The position of India as a producer of wheat in the world has declined; contributing nearly 9 per cent of the world production at the beginning of the century, she now produces only 4 per cent of the world crop if we exclude the production in the U.S.S.R. From the position of a sizable exporter of roughly about a million tons annually at the turn of the century, exports dwindled till these stopped completely during World War II; today India imports considerable quantities of this grain to meet her internal food deficit and in making efforts to stabilize her economy.

TABLE I. AREA AND PRODUCTION OF WHEAT IN DIFFERENT COUNTRIES OF THE WORLD

Continent and country	Area ('000 hectares)					Yield ('00 kg./hectare)					Production ('000 metric tons)				
	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 Average)	1960–61	1961–62	1962–63	1963–64
EUROPE															
Albania[1]	94[2]	90	126	139	..	9·4[2]	7·2	7·7	10·5	..	89[2]	64	98	146	..
Austria	204	277	276	270	275	17·1	25·3	25·8	26·1	25·1	348	702	712	706	690
Belgium[1]	163	210	212	212	204	32·2	37·7	34·8	39·8	37·7	525	799	738	844	770
Bulgaria[1],[3]	1,432	1,257	1,317	1,249	1,138	12·4	19·0	15·4	16·7	15·9	1,776	2,389	2,034	2,086	1,892
Czechoslovakia[1]	785	646	641	670	717	19·0	23·3	27·4	24·5	24·6	1,493	1,503	1,656	1,644	1,766
Denmark	78	82	105	154	135	36·5	39·0	41·3	41·8	36·7	285	320	434	644	495
Finland	171	181	237	286	239	15·4	20·4	19·4	14·8	16·6	264	368	461	422	397
France	4,264	4,358	3,997	4,570	3,850	18·3	25·2	23·9	30·7	26·6	7,791	11,014	9,574	14,054	10,249
Germany															
Eastern	472	418	377	423	426	26·2	34·8	27·5	31·1	30·0	1,243	1,456	1,038	1,315	1,230
Federal Republic[1]	1,020	1,396	1,397	1,319	1,382	26·2	35·6	28·9	34·8	35·1	2,669	4,965	4,038	4,592	4,856
Greece	878	1,143	1,067	1,091	935	10·2	14·8	14·9	16·2	14·8	894	1,692	1,594	1,770	1,387
Hungary[3]	1,385	1,051	1,014	1,095	976	13·8	16·8	19·1	17·9	15·6	1,909	1,763	1,936	1,959	1,523
Ireland	144	148	140	127	94	22·7	31·7	33·6	34·6	32·0	327	469	470	439	301
Italy	4,705	4,553	4,345	4,556	4,394	15·2	14·9	19·1	20·8	18·5	7,170	6,794	8,301	9,497	8,127
Luxembourg	17	20	20	18	18	18·0	25·0	25·0	24·0	27·0	30	51	49	44	50
Malta	2	2	2	2	2	12·4	13·5	13·5	13·5	13·5	3	3	3	3	3

Netherlands	89	126	123	133	126	36·5	46·6	39·3	45·5	42·0	325	590	482	603	530
Norway[3]	28	9	10	10	7[7]	20·6	25·1	23·3	20·8	25·4	58	23	27	20	18
Poland	1,464	1,361	1,401	1,393	1,541	12·5	16·9	19·9	19·4	19·9	1,833	2,303	2,792	2,700	3,067
Portugal	689	738	658	729	740	7·2	6·7	6·5	8·9	8·0	499	492	430	645	592
Rumania[3]	2,728[4]	2,836	2,969	3,043	2,874	10·2[4]	12·2	13·4	13·3	13·2	2,486	3,450	3,990	4,054	3,799
Spain[1]	4,162	4,244	3,891	4,263	4,247	8·7	8·3	8·8	11·3	11·4	3,625	3,528	3,438	4,820	4,866
Sweden	323	338	275	314	244	20·9	24·3	29·5	27·7	26·1	677	824	812	872	637
Switzerland[1]	98	109	116	109	107	26·5	34·5	27·1	38·5	28·8	260	378	316	420	303
United Kingdom	881	851	739	913	780	27·2	35·7	35·4	43·5	39·1	2,397	3,040	2,614	3,974	3,046
Jersey	..	..	..	..	..	26·8[5]	26·5	26·9	27·8	..	1[5]	..	..	..	..
Isle of Man	..	..	..	..	..	25·1[5]	25·2	26·0	22·4	25·4	1[5]	1	1	1	..
Yugoslavia[1]	1,819	2,064	1,964	2,134	2,144	12·0	17·3	16·2	16·5	19·3	2,171	3,574	3,174	3,514	4,143
Total	28,010	28,510	27,420	29,220	27,770	14·7	18·4	18·7	21·1	19·8	41,150	52,550	51,220	61,790	54,890
U.S.S.R.[3]	42,633[2]	60,393	63,000	67,411	64,600	8·4[2]	10·6	10·6	10·5	..	32,750[4]	64,299	66,483	70,778	..
NORTH & CENTRAL AMERICA															
Canada	10,507	9,930	10,245	10,852	11,155	12·8	14·2	7·5	14·2	17·6	13,443	14,108	7,713	15,392	19,689
Guatemala	35[4]	31	34	..	..	5·8[4]	6·8	7·3	..	..	20[4]	21	25	..	..
Honduras	2	2	2	2	2	5·8	8·4	5·7	5·7	5·6	1	1	1	1	1
Mexico	604	840	837	752	817	8·8	14·2	16·8	20·0	21·9	534	1,190	1,402	1,502	1,786
United States of America	27,756	21,001	20,862	17,620	18,295	11·2	17·6	16·1	16·9	17·0	31,066	36,939	33,604	29,765	31,080
Total	38,900	31,800	31,980	29,260	30,300	11·6	16·4	13·4	16·0	17·4	45,060	52,260	42,740	46,680	52,580

TABLE I. AREA AND PRODUCTION OF WHEAT IN DIFFERENT COUNTRIES OF THE WORLD (*Contd.*)

Continent and country	Area ('000 hectares)					Yield ('00 kg./hectare)					Production ('000 metric tons)				
	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64
SOUTH AMERICA															
Argentina	4,487	3,599	4,198	3,438	5,406	11·5	11·0	12·1	14·6	15·0	5,175	3,960	5,100	5,020	8,120
Bolivia	60^{6}	..	..	..	..	6·1^{6}	..	..	..	..	37^{6}	40	67	..	..
Brazil^{3}	671	1,141	1,022	743	793	7·4	6·3	5·3	9·2	4·9	498	713	545	680	392
Chile^{3}	791	838	849	843	852	11·9	13·4	12·6	15·1	15·3	942	1,123	1,071	1,275	1,304
Colombia	173	166*	160*	150*	113*	7·2	8·7*	8·9*	10·8*	8·0*	124	145*	142*	162*	90*
Ecuador	54^{4}	..	79	85	67	4·2^{4}	..	9·9	9·2	10·0	24	58	78	78	67
Paraguay	2	12	8	10	9	7·8	7·5	9·0	7·0	13·3	1	9	7	7	12
Peru^{3}	158	154	153	154	149*	9·2	10·0	10·0	9·9	10·1	146	154	154	153	150*
Uruguay	526	520	436	400	357	9·2	8·1	8·5	11·3	6·6	469	420	372	452	236
Venezuela	10^{2}	2	2	1	2	4·7^{2}	5·1	5·4	5·3	5·2	5	1	1	1	1
Total	6,930	6,550	6,990	5,900	7,830	10·7	10·1	10·8	13·4	13·3	7,420	6,620	7,540	7,900	10,440
ASIA															
Afghanistan	..	2,230	..	..	..	..	10·2	..	..	..	1,700^{7}	2,279	..	2,279	1,967
Burma	14^{2}	27	24	36	58	2·9^{2}	3·7	3·1	4·1	5·6	4^{2}	..	7	15	32
China, Taiwan	14	25	22	20	14	9·6	18·1	20·3	20·7	13·0	13	46	44	42	19
Cyprus	75	78*	79*	68	..	6·4	5·9*	5·9*	9·5	..	48	46	47*	64	80*
India	9,290	13,380	12,969	13,520	13,657	6·6	7·7	8·5	8·9	7·9	6,087	10,324	10,992	12,039	10,829

Iran	2,0804*	3,314	..	..	..	9·04*	7·8	..	..	..	1,860*	2,590*	2,803*	2,700*	2,900*
Iraq	936	1,271	1,346	1,591	1,705	4·8	4·6	6·4	6·8	2·7	448	592	857	1,085	468
Israel3	344	59	63	48	52	6·94	7·0	10·5	10·9	10·1	214	41	66	52	55
Japan3	743	602	649	642	584	18·5	25·4	27·4	25·4	12·3	1,375	1,531	1,781	063,1	716
Jordan	182	100	225	224	104	7·0	4·4	6·1	5·0	7·3	127	44	138	112	76
Korea, Republic3	95	124	124	133	37	8·9	12·7	13·8	12·3	5·5	84	158	171	164	75
Lebanon	70	54	69	69	55	7·3	7·4	10·0	11·0	10·9	51	40	68	75	60
Pakistan3	4,218	4,934	4,696	4,982	5,096	8·7	8·0	8·2	8·2	8·3	3,685	3,938	3,847	4,066	4,215
Ryukyu Islands	16	1	1	..	..	6·16	9·1	11·1	12·7	16·8	16	1	1	1	..
Saudi Arabia	186*	..	..	..	43	8·76*	..	..	..	19·9	156	..	..	..	85
South Arabia, Federation	24	4	3	3	5	15·44	18·5	14·1	14·1	22·3	34	7	5	5	10
Syria	994	1,550	1,315	1,417	1,559	7·7	3·4	5·7	9·7	7·6	762	555	755	1,374	1,190
Turkey1,3	4,770	7,831	7,846	7,931	7,982	10·0	11·0	9·1	10·8	12·7	4,771	8,590	7,135	8,580	10,137
Total	25,770	35,770	34,930	36,380	36,790	8·2	8·6	8·9	9·5	9·0	21,150	30,910	31,170	31,110	33,000
China Mainland3,4	23,0504	..	..	..	..	6·94	..	..	..	..	15,9104	..	..	..	..
AFRICA															
Algeria	1,597	1,920	1,594	1,873	2,020	6·2	7·9	3·9	8·0	7·8	996	1,509	682	1,580	1,580
Basutoland	498	67	..	..	..	10·18	8·7	..	..	..	508	58	..	..	..
Chad	14	..	1	1	..	13·34	..	11·1	12·7	..	16	..	2	1	..
Congo (Leopoldville)	4	..	..	..	..	8·7	..	..	..	..	3	..	..	..	..
Ethiopia9	109	13	364	371	..	3·99	5·0	7·0	7·0	..	179*	117	255	260	266
Kenya10	103	101	91	113	114	10·9	12·8	9·2	7·4	10·0	112	129	84	81	114

TABLE I. AREA AND PRODUCTION OF WHEAT IN DIFFERENT COUNTRIES OF THE WORLD (*Contd.*)

Continent and country	Area ('000 hectares)					Yield ('00 kg./hectare)					Production ('000 metric tons)				
	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64	1948–49 to 1952–53 (Average)	1960–61	1961–62	1962–63	1963–64
Libya															
Cyrenaica	..	89	63	..	..	..	1·4	2·8	..	..	4^{2}	13	18	28	..
Tripolitania	23	133	42	67	65	2·9	1·5	2·9	1·9	2·8	7	20	12	13	18
Fezzan	1^{6}	1	..	..	..	15·8^{6}	8·1	..	..	..	1^{4}	1	..	..	..
Malawi	1^{8}	..	..	..	..	6·1^{8}	..	..	..	..	1^{2}	1	..	..	..
Mali	2^{2}	1	2	..	..	10·0^{4}	14·0	15·0	..	..	2^{4}	1	4	..	..
Morocco	1,287	1,645	1,527	1,456	1,653	6·1	5·9	3·9	8·6	7·2	786	974	601	1,256	1,196
Niger	1^{4}	1	1	1	1	14·8^{4}	15·2	12·3	12·0	12·8	1^{4}	1	1	1	1
South Rhodesia^{3,10}	..	1	1	1	..	7·3	19·7	14·7	15·9	..	..	1	1	..	..
Ruanda-Urundi (former)	17	5	..	..	..	7·0	6·6	..	..	..	12	3	..	..	..
Rwanda	..	..	2	2	..	..	..	7·2	8·0	..	..	..	1	2	..
South Africa^{10}	927	894	1,054	1,012	1,200*	6·0	8·1	8·4	6·9	..	555	771	884	700	882
South-West Africa	..	..	1	..	..	12·0^{4}	..	9·9	12·0	..	1^{4}	..	1	..	..
Sudan	13	16	16	23	23	11·8	15·2	16·1	13·5	16·0	15	25	26	31	37
Tanganyika	12^{4}	..	..	..	..	5·8^{4}	..	..	..	..	6	12	6	18	18
Tunisia	917	1,355	943	849	..	4·9	3·2	2·9	4·6	..	452	439	243	393	570
Uganda	1^{2}	..	..	..	..	..	..	..	..	..	..	..	..	..	..
United Arab Republic^{3}	605	612	581	611	661	18·4	24·5	24·6	26·1	25·9*	1,113	1,499	1,436	1,593	1,714*
Total	6,040	7,250	6,400	6,600	7,200	7·1	7·8	6·7	9·0	9·1	4,300	5,620	4,280	5,960	6,520

Australia³	4,620	5,438	5,958	6,664	6,667	11·2	13·7	11·3	12·5	13·4	5,161	7.149	6.727	8.353	8,924
New Zealand	51	76	75	91	82	27·3	33·5	28·3	27·4	33·0	139	253	213	249	271
Total	4,670	5,510	6.030	6,750	6,750	11·3	14·0	11·5	12·7	13·6	5,300	7,700	6.940	8,600	9,200
World Total	169.800	202,300	202,800	208,000	208,200	10·1	12·1	11·7	12·6	12·0	171,100	245,000	236,900	263,100	219,600
Regional Totals															
Europe	28,010	28,510	27,420	29,220	27,770	14·7	18·4	18·7	21·1	19·8	41,150	52,550	51,220	61,770	54,890
North America	38,260	30,930	31,110	28,470	29,450	11·6	16·5	13·3	15·9	17·2	44,510	51,050	41,320	45,160	50,770
Latin America	7.570	7,420	7,860	6,690	8,680	10·5	10·6	11·4	14·1	14·1	7,980	7,840	8,960	9,430	12,250
Near East	11,970	17,370	16,990	17,680	17,950	9·1	9·4	9·3	10·2	10·5	10,950	16.370	15,740	18,060	18,830
Far East	14.540	19,250	18,640	19.490	19,710	7·9	8·4	9·1	9·3	8·1	11,310	16,090	16,930	18,040	15,970
Africa	5,290	6,400	5,700	5,800	6,340	6·0	6·3	4·9	7·4	7·4	3.160	4,060	2,790	4.300	4,720
Oceania	4,670	5,510	6.030	6.760	6,750	11·3	14·0	11·5	12·7	13·6	5.300	7.700	6,940	8,600	9.200

1, Includes spelt. 2, Average of three years. 3, Sown area. 4, Average of four years. 5, 1952–53. 6, Average of two years. 7, 1948–49. 8, 1949–50. 9, Area and yield refer to Eritrea only. 10, On farms and estates. *Unofficial figure.

Source : *Production Yearbook.* 1964. Volume 18. F.A.O., Rome (1965).

Although four species of wheat, viz., *Triticum aestivum* (bread wheat), *T. durum* (macaroni wheat), *T. dicoccum* (emmer wheat) and *T. sphaerococcum* (dwarf wheat) are grown in India, the last species has almost gone out of cultivation and *T. dicoccum* is grown only in small pockets in the states of Bombay, Mysore, Andhra Pradesh and Madras. The main wheat species under cultivation in India are *T. aestivum* and *T. durum;* of these the former occupies by far the largest area. The *aestivum* types occupy the extensive wheat-growing areas of the Punjab, Uttar Pradesh, Bihar, Madhya Pradesh and Rajasthan, while *T. durum* types are grown mainly in some parts of Bombay. They are also grown to a lesser extent in certain districts of Madhya Pradesh, the southern districts of U.P., and a few districts of Rajasthan and West Bengal. Each of the commonly cultivated species of wheat is represented by an innumerable number of botanical varieties. The area under wheat and total production in each of the states in India is indicated in Table II.

From the standpoint of the growing season, two main types of wheat, namely, the 'winter wheats' and the 'spring wheats', are generally distinguished. These

TABLE II. ESTIMATED AREA UNDER WHEAT AND PRODUCTION IN DIFFERENT STATES OF INDIA

State	Area ('000 acres)			Production ('000 tons)		
	1961–62	1962–63	1963–64	1961–62	1962–63	1963–64
Andhra Pradesh	48	47	48	4	5	4
Assam	9	10	9	3	3	3
Bihar	1,727	1,768	1,685	514	519	366
Gujarat	972	1,007	1,028	350	298	361
Jammu & Kashmir	418	422	427	102	107	112
Madhya Pradesh	7,849	7,765	7,957	2,143	2,067	1,845
Madras	3	3	3	1	1	1
Maharashtra	2,196	2,263	2,210	390	456	338
Mysore	770	754	740	69	81	87
Orissa	22	23	23	4	4	4
Punjab	5,536	5,593	5,740	2,740	3,007	2,739
Rajasthan	3,192	2,071	2,773	1,248	1,068	847
Uttar Pradesh	10,131	9,980	9,677	4,089	3,186	2,692
West Bengal	113	121	121	34	30	30
Delhi	72	71	80	32	29	31
Himachal Pradesh	352	357	356	126	95	95
Total	33,410	33,255	32,878	11,849	10,956	9,555

NOTE : Wheat is not grown to any appreciable extent in Kerala, Manipur, Tripura, Nagaland, Andaman and Nicobar, and Laccadive, Minicoy and Amindivi Islands.
Source : *Agricultural Situation in India* **18**(5), 1963.

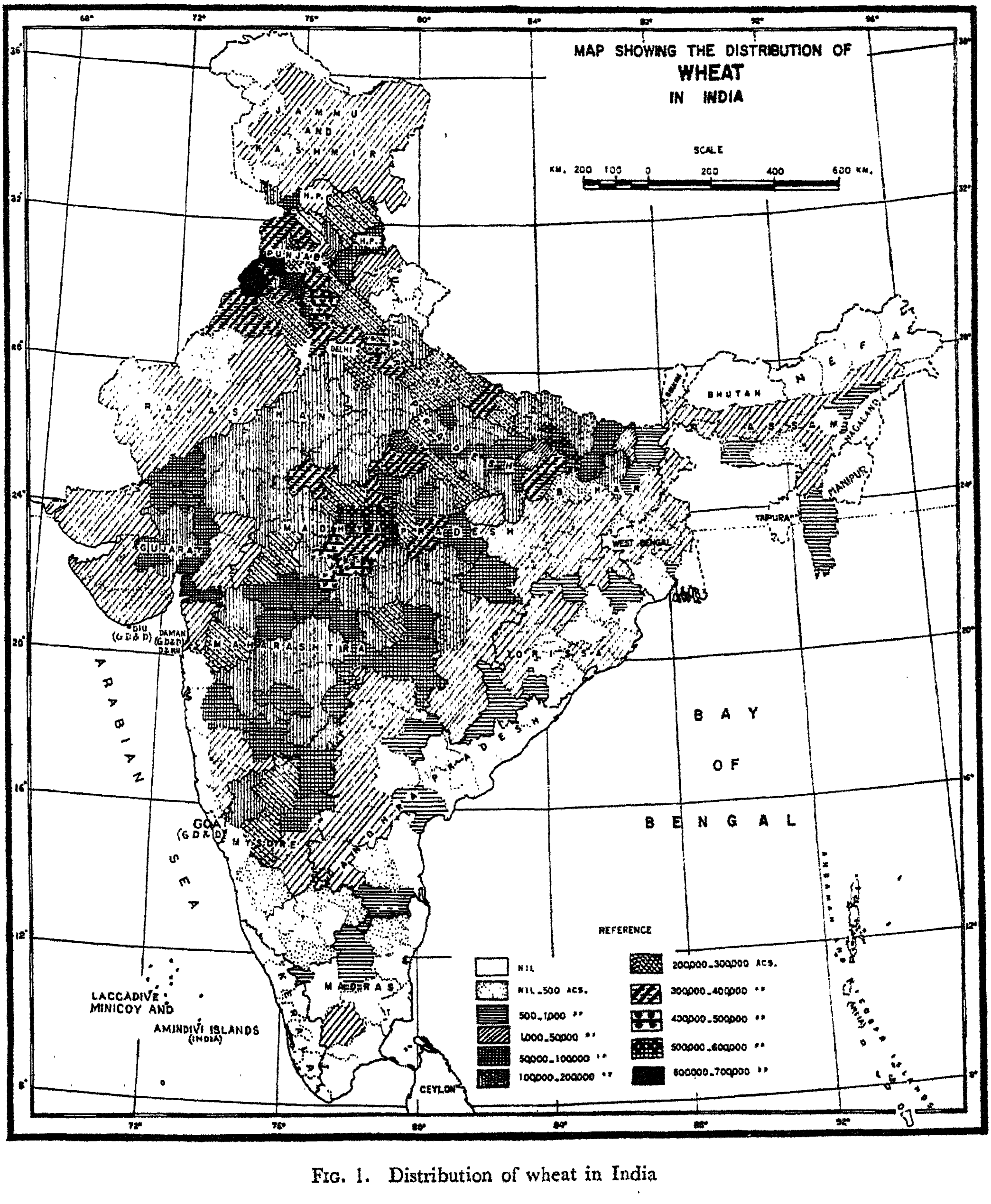

FIG. 1. Distribution of wheat in India

terms are mostly in use in the western countries where the crop is raised in winter as well as in summer. Varieties with a long period of growth and with greater requirements of low temperatures in the early stages of growth are sown in September or October. They pass the severe winter covered by the snow, come into ear in spring and mature during the summer months of June and July. These are the 'winter wheats'. The 'spring wheats' are characterized by their short growing period; they do not require very low temperatures in the early stages of their growth. They are sown in April or May and harvested in August or September. In India, the two features are combined, inasmuch as short-duration varieties with 'spring' type of growth are raised during the *rabi* or winter season. It is only in some hills in South India that wheat is grown in winter as well as in summer, but this area is very small.

The duration of the wheat crop and the time of sowing and harvesting vary considerably in India. The longest growing period is in the hills of northern India, where it is sown in the month of October and harvested in June or July. In the plains, the period of growth is the longest in the north-western region and becomes shorter towards the north-east and the south. The duration of the growing season is approximately 180 days in the hills of North India, 160 days in the north-west, 120–140 days in Uttar Pradesh, Bihar and western India, and 100 days in peninsular India. In the Punjab, wheat sowings begin in November and are over by the end of the month; late sowings may extend up to the end of December. In Uttar Pradesh and Bihar sowings are 15 days earlier than in the Punjab. In central and western India sowings are completed by the end of October, while in the Deccan region sowing is done in September or during the first fortnight of October.

The crop is largely irrigated in the Punjab, parts of U.P., Bombay, Rajasthan and Madhya Pradesh. In Bihar, eastern U.P. and West Bengal it is generally raised as a rainfed crop. Taking the country as a whole, the greater part of the area is not covered by irrigation and the lack of an adequate water supply is an important limiting factor responsible for generally low yields. However, the facilities for irrigation are being increased, especially as a result of the large river valley projects which have been taken up in a number of states. The crop on the average requires three to four irrigations of three to four acre-inches each. If there is adequate winter rain, the number of irrigations can be reduced correspondingly.

A reference may be made here to the hill wheat of India. Wheat is one of the most important food crops in the North Indian mountains. This is due to the fact that it is the only protein-rich winter cereal that is admirably adapted for cultivation under climatic conditions prevailing in this extensive strip of mountainous territory, extending from Kashmir in the west to Assam in the east. Here, the crop is grown on terraced fields cut across the steep slopes of the mountain ranges (Plates 1, 2). The soils vary widely in physical and chemical properties; besides, topography, altitude and aspect conditions change even within a single square mile. Wheat cultivation extends from the foot-hills (less than 1,000 ft. above sea-level) to about 10,000 ft. above sea-level.

Wheat is consumed in India mostly in the form of *chapattees* (unleavened bread). The grains of *durum* and *dicoccum* wheats are usually used mainly for the preparation of semolina (*suji*, *rava*) and vermicelli (*semya*, *sewayya*).

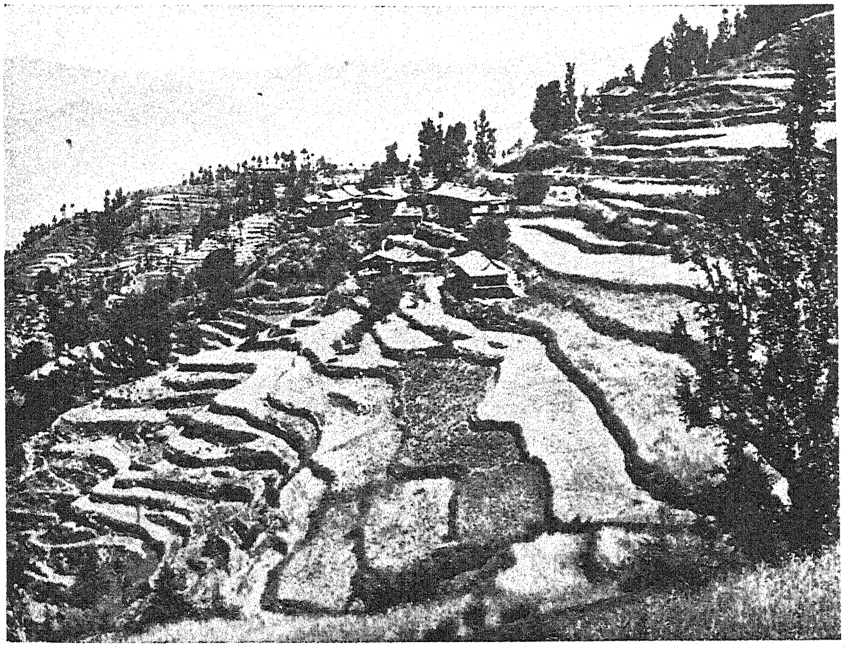

PLATE 1. Terrace cultivation in the hills

PLATE 2. Threshing of wheat in the hills

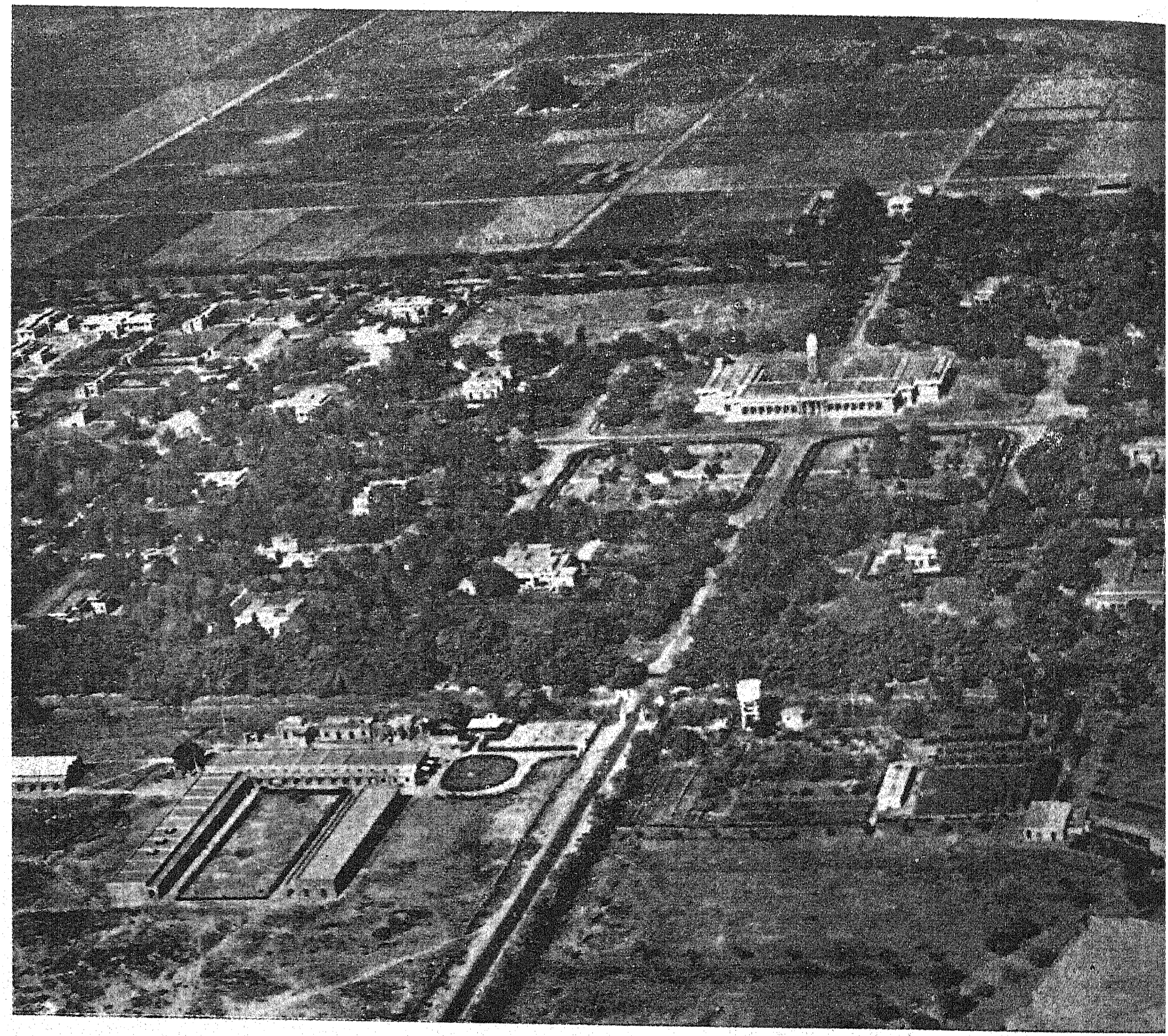

PLATE 3. Campus of the Indian Agricultural Research Institute, New Delhi (an aerial view)

The demand for food grains in India has been increasing and will continue to increase with the increase in population and the rise in the standard of living. The average acre yields of wheat in India are distressingly low, being only a little over 600 lb. per acre, when compared with the yields in other countries. However, with the introduction of improved varieties and irrigational facilities this figure is bound to rise. The high yields ranging from 5,000 to 6,000 lb. per acre obtained by the winners of crop competitions (*Krishi Pandits*) in recent years give an indication of the vast scope that exists for increasing wheat production.*

While looking into the cause for the general low yields, one has to keep in mind the shorter growing period of the crop in India. In Europe and North America, the winter wheat crop stands in the field for nine to ten months after sowing while in India the growing season is only four to six months. In the hill regions of northern India, however, the crop stands for a longer duration in the field but this is offset by the relatively low soil fertility; but in any case the area in the hills is too small to materially affect the national average yield figure. Other reasons for the poor yields in the country are the cultivation of the crop in 'marginal' areas not really suitable for wheat production and lack of irrigation facilities (more than 70 per cent of the wheat crop is raised under rainfed conditions) and very limited use of fertilizers and modern agricultural practices. Again, diseases of wheat often bring about a considerable reduction in yield. Insect pests also cause some losses but in India loss due to pest infestation occurs more during storage than during plant growth. Attempts are being made to increase the average yield in two main ways : (1) by enhancing production through improved methods of cultivation as well as through increasing the inherent yielding capacity of the cultivated varieties, and (2) by avoiding the loss caused by pests and diseases through the adoption of proper control methods as well as by the production and use of varieties of wheat possessing resistance to the more serious diseases and pests. The work done in India, aimed at achieving these ends, is dealt with in some detail in the succeeding chapters.

Scientific research. Scientific research on various aspects of wheat has been in progress in the country from the beginning of the century, both at the Indian Agricultural Research Institute (Plate 3), formerly known as the Imperial Agricultural Research Institute, and the State Departments of Agriculture. From time to time workers in the Universities have also contributed significantly to the work on wheat. There have also been instances of scientists not attached to any official organization having carried out investigations relating to this crop. The work on wheat breeding, with particular reference to breeding for rust resistance, has been coordinated by the Indian Council of Agricultural Research during the last two and a half decades. In addition to arranging for the coordination, the Council itself contributed handsomely to the progress of wheat-breeding work by making grants to the Indian Agricultural Research Institute and to some of the State Departments of Agriculture. Very recently the Council has approved proposals for strengthening and expanding the work on wheat to cover all aspects.

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*The performance of dwarf, fertilizer-responsive varieties like Sonora, Lerma Rojo and others introduced in recent years from Mexico has amply demonstrated the potentialities that exist for high wheat yields under Indian conditions. In the countrywide National Demonstration Plots and in experimental fields these varieties have given yields of about 6,000–7,000 lb. per acre while in cultivators' fields yields of 4,000–4,500 lb. per acre have been reported.

II

ORIGIN AND HISTORY

The exact time and mode of origin of wheat is lost in the mist of antiquity, as indeed is the case with most of our staple food crops. There is no doubt that the ancient civilizations of Babylonia, Crete, Egypt, Greece and Rome were based on wheat as one of the principal food plants while the Chinese grew this cereal as long ago as 2700 B.C. The ancients, who were unaware of the slow evolution of man from a savage to a highly civilized being, attributed the origin of wheat to a supernatural agency. The Chinese regarded wheat as a direct gift from heaven, while the Egyptians believed its introduction to have been due to the Goddess Demeter and Tryptolemus. Buller (1919) refers to the annual festival of the Cerealia, which was celebrated by the worshippers of Ceres, as Demeter came to be known in Italy. At the festival held in August, after fasting for nine days, women clothed in white and adorned with crowns made from ripe ears of wheat made offerings to the Goddess of the first fruits of the harvest. Furthermore, the fact that samples of wheat have been found in the prehistoric human habitations, notably in the rubbish heaps of lake dwellings in both Italy and Switzerland, provides convincing evidence that this cereal was cultivated even by prehistoric man.

These and other evidences help us to form a hazy outline of the history of this most important cereal. Such a picture will necessarily have to be based on linguistic evidence as well as on archaeological discoveries. Some of the more important of these are considered below.

The available linguistic evidence does not appear to be as instructive in tracing the history of wheat as it has been in following the development of other important cereals like rice. The most ancient languages mention wheat, but under different names. Whether we assume that these names, with the languages in which they are found, became differentiated from a common parent, or whether we assume that wheat evolved and spread over the old world so independently that its name did not accompany its progress, we must conclude that it must have developed at a time antedating our oldest language. The Chinese classics of the Chou period (about 1000 B.C.) give descriptions of wheat varieties which are possibly 21-chromosome bread wheats, since 14-chromosome wheats are recent introductions to China.

Archaeological evidence enables us to fix certain periods of time at which some of the types of wheat, presently being cultivated, had already evolved more or less to their present form (Table III). All of the many species of wheat (Plates 4, 5, 6) known at the present time have come to us with comparatively little change, as judged by morphological characters, out of the distant past. According to Buller (1919), wheat has been found in a brick of the pyramid of Dashor in Egypt, to which Unger assigns the date of

TABLE III. CHROMOSOME NUMBER, GENOME SYMBOL AND EARLIEST EVIDENCE OF 15 SPECIES OF WHEAT (*After* Mangelsdorf, 1953)

Latin name	Common name	Chromosome number	Genome symbol	Earliest evidence
T. boeoticum (= *T. aegilopoides*)	Wild einkorn	7	A	Pre-agricultural
T. monococcum	Einkorn	7	A	4750 B.C.
T. dicoccoides	Wild emmer	14	AB	Pre-agricultural
T. dicoccum	Emmer	14	AB	4000 B.C.
T. durum	Macaroni wheat	14	AB	100 B.C.
T. persicum	Persian wheat	14	AB	No pre-historic remains
T. turgidum	Rivet wheat	14	AB	—do—
T. polonicum	Polish wheat	14	AB	17th century
T. timopheevi	—	14	AG (AS)	20th century
T. aestivum	Common wheat	21	ABD	Neolithic period
T. sphaerococcum	Dwarf wheat	21	ABD	2500 B.C.
T. compactum	Club wheat	21	ABD	Neolithic period
T. spelta	Spelt	21	ABD	Bronze age
T. macha	Makha wheat	21	ABD	20th century
T. zhukovskyi	—	21	AAB	20th century

3359 B.C., while the heads of emmer (*Triticum dicoccum*) found in great quantity in the sarcophagi of ancient Egypt differ little in external form from present-day Mediterranean forms. Only one of the Western European wheats, the so-called 'square head', has been the product of recent evolution, at least as regards its extensive culture. It is believed to have had its origin from a cross between the club and soft wheats.

A wheat found in the neolithic store-chambers in Hungary has been identified as club wheat. Impressions of grains of bread wheat, either common or club, have been found in the neolithic Dolmen period, dated between 300 and 2300 B.C. The recovery of carbonized kernels of wheat from excavations at ancient centres of human civilization where evidence from pottery, implements and other factors enables the dating to be more precise, shows that even in those distant times varieties very similar to those in cultivation at present were being grown. Carbonized kernels of wheat have been recently discovered by Robert Braidwood, archaeologist of the University of Chicago, at the 6,700-year-old site of Jarmo in eastern Iraq. This is one of the oldest villages yet discovered, and may have been one of the birth places of man's agriculture. According to Mangelsdorf (1953), who compared these carbonized kernels with modern wheat kernels carbonized artificially in order to simulate the archaeological specimens, the resemblance between the ancient and modern grains is remarkable. Among the two types of kernels identified from the Jarmo site, one turned out to be identical with a wild wheat, *T. aegilopoides*, still growing in north-east Europe, and the other was almost exactly like the present-day cultivated wheat of the type called einkorn (*T. monococcum*). Whether these two are the only wheats occurring at this ancient site remains to be seen.

Kernels of dwarf wheat (*T. sphaerococcum*) have been found at the most ancient site in India, Mohenjo-Daro, dated 3000 B.C. (Plate 7). The oldest wheat remains in the Soviet territories are those of Turkemenia, dating from the 5th century B.C. and pertaining to *T. dicoccum*. It was sometimes, as happens in certain areas even today, accompanied by *T. monococcum*. *T. aestivum* has been recorded in the remains dating from the 4th century B.C. in Turkemenia and from the 3rd century B.C. in Transcaucasia and the Ukarine.

The evidence obtained from archaeological researches agrees with, or at least is not contradicted by, the internal evidence afforded by the elegant tool of genome analysis. This has shown conclusively that the earliest type of wheats should belong to the 7-chromosome einkorn series, while 21-chromosome bread wheat series constitutes the latest step in the evolution of the wheat complex (*See* Chapter 4). Our confidence in the archaeological evidence is strengthened when we find that the earliest sites, as that of the 6,700-year-old site at Jarmo in Iraq, yield types similar to einkorn series, while the earliest record of types resembling the bread wheat group is nearly two to three thousand years later as at Mohenjo-Daro in India (Plate 7).

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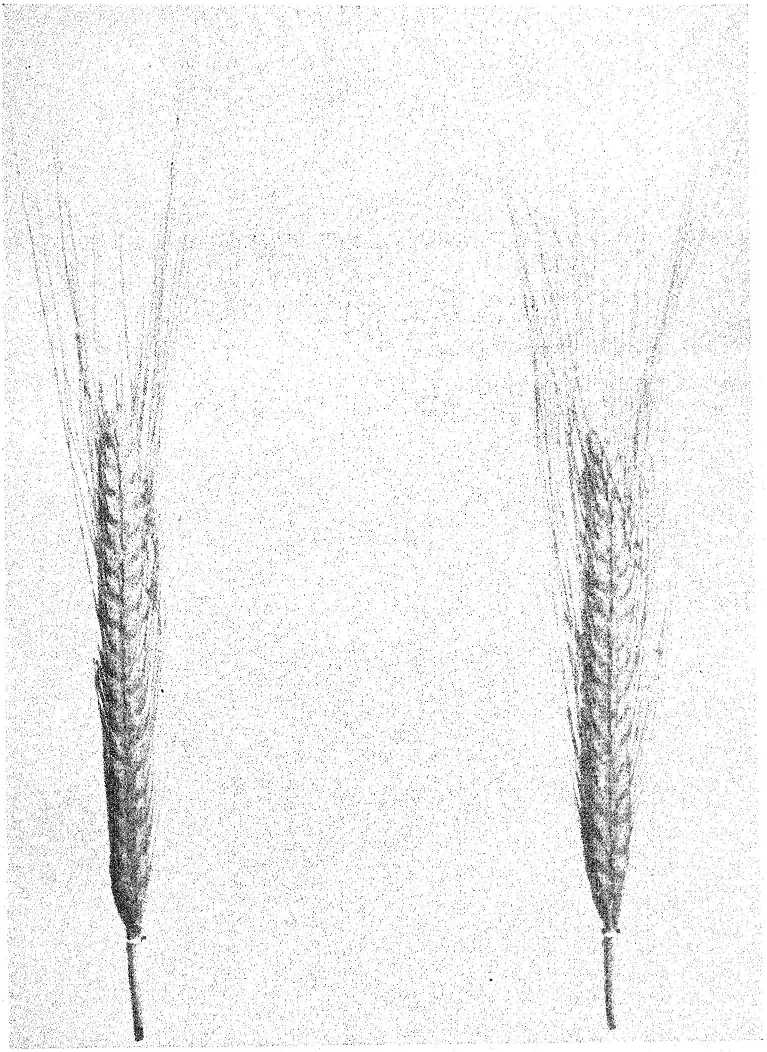

T. boeoticum (= *T. aegilopoides*) *T. monococcum*

PLATE 4. Diploid species of *Triticum*

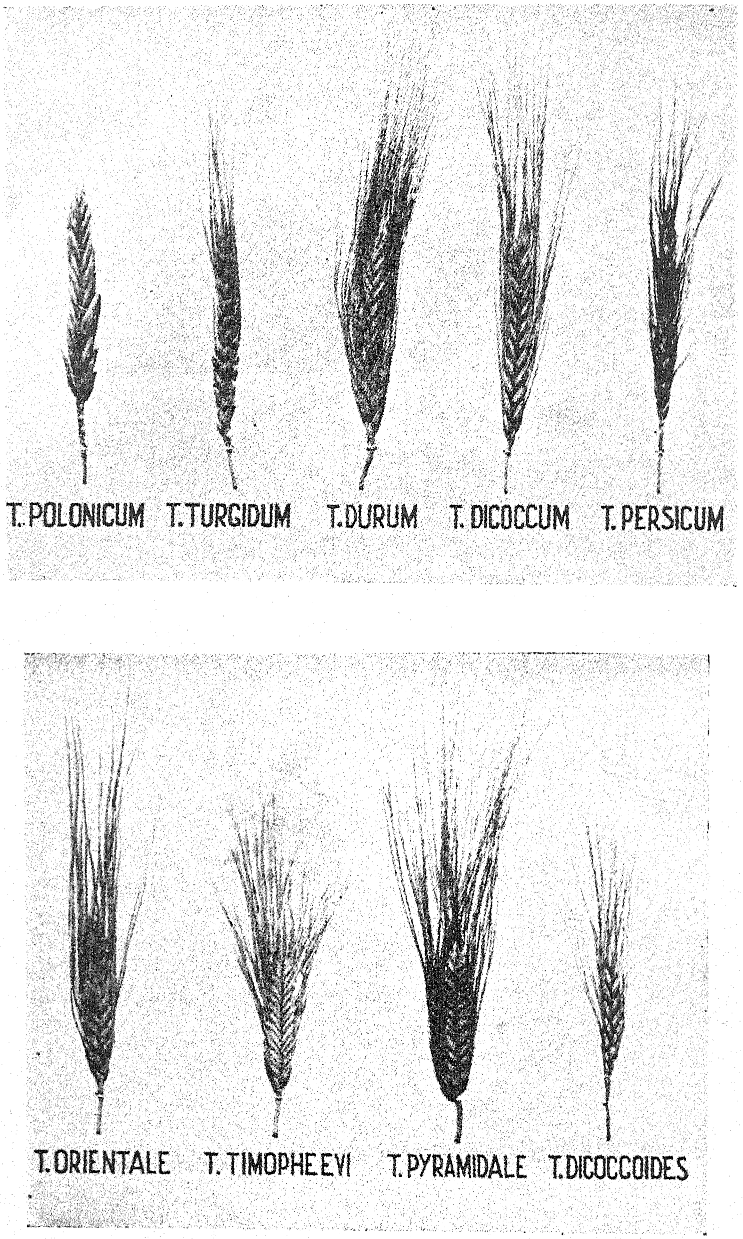

PLATE 5. Tetraploid species of *Triticum*

III

SYSTEMATICS AND MORPHOLOGY

Much work has been done on the taxonomy and inter-relationship of wheat species since 1927 when Vavilov proposed his theory that gene-centres are also centres of origin of cultivated plants. Vavilov's views stimulated the organization of plant-collecting expeditions to the Karakoram and Hindu Kush regions for the purpose of collecting material of wheat and its wild relatives. German botanists like Scheibe and Troll made rich collections during such expeditions and from an analysis of this material Elizabeth Schiemann has made excellent contributions to our knowledge of the history of cultivated cereals. From her studies, Schiemann (1951) concluded that Vavilov's theory of gene-centres being also centres of origin, though valid in many cases, is not always so. It holds good for *T. monococcum* with its centre in Anatolia, for the six-rowed barleys in east Asia and probably also for *T. dicoccum* in Transcaucasia. The Hindu Kush area is the centre of diversity of hexaploid wheats and their origin as amphidiploids of emmer × *Aegilops squarrosa* must have occurred in the common area of the two parents, which points again to the Transcaucasian centre. But there are also other secondary centres of diversity, such as Abyssinia. Extensive collections of members belonging to the *Sitopsis* section of *Aegilops* and of *Ae. squarrosa* have been made in recent years by the Japanese expeditions to Pakistan, Afghanistan, Iran and the eastern Mediterranean region (Kihara and Tanaka, 1958). Results from studies carried out in this material are expected to throw further light on the question of the origin of the B genome. Thus, the era of collecting expeditions inaugurated by Vavilov has enriched our knowledge of crop evolution and has led to the introduction of genetics and cytology into the study of crop plants. Having stagnated since de Candolle, the study of crop plants was raised to a position of importance and great interest by the work of Vavilov.

TAXONOMY AND NOMENCLATURE

The wheat plant is an annual cereal belonging to the genus *Triticum* of the family Gramineae. For a long time many authors included the genus *Triticum* in the tribe Hordeae but Pilger (1954) showed that the earliest name for the tribe, validly published as a tribe name, is Triticeae, which was published in 1823 by Dumortier. This tribe includes *inter alia* the genera *Triticum*, *Aegilops*, *Hordeum* and *Secale*. The sub-tribe Triticineae includes *Triticum*, *Aegilops*, *Agropyron*, *Secale*, *Haynaldia* and *Elymus*. As will be discussed later, intergeneric hybrids have been obtained by several authors in the sub-tribe Triticineae.. Stebbins (1956) gave a list of such hybrids and concluded, on the basis of the available cytogenetic data, that " the maintenance of *Triticum* and *Aegilops* as separate genera becomes an absurdity ". Stebbins considered that all of the genera of the tribe should be united into one genus, but that much more information on relationships was required before this could be done. Riley *et al.* (1958) also suggested that "ideas on the phylogeny of wheat must be re-adjusted to associate the genera *Triticum* and *Aegilops* more closely together". Bowden (1959), in a recent taxonomic treatment of the genus *Triticum*, included species of *Aegilops* also in this genus.

Nomenclature of hexaploid wheats. A number of wheats with 2n = 42 have been recognized: *T. aestivum* L., *T. spelta* L., *T. compactum* Host, *T. macha* Dek. and Men., *T. sphaerococcum* Perc., *T. vavilovi* Jakubz. and *T. zhukovskyi* Men. et Er. Sears (1948) gave the genomic formula AABBDD for all these six species. All these wheats are cultivated and can be inter-crossed. Cytogenetic evidence has shown that: (a) *T. aestivum* and *T. compactum* are separated by the gene *C* located on chromosome XX (2D); (b) *T. aestivum* is separated from *T. sphaerococcum* by the factor *S* located on chromosome XVI (3D); and (c) *T. aestivum* and *T. spelta* are separated by the gene *Q* present on chromosome IX (5A). Sachs (1953) showed that *T. macha* also is closely related to the other hexaploid species. Until recently, very little genetical knowledge was available concerning the relationship between *T. vavilovi* and other hexaploid species. Singh *et al.* (1957) recently showed that the length of the rachilla, in which *T. vavilovi* primarily differs from the other hexaploid species, is governed by only two genes. Hence, they pointed out that *T. vavilovi* is quite closely related to *T. aestivum.* Mac Key (1954) concluded, from the available cytogenetical and cyto-taxonomic data, that there is no justification for retaining separate specific status for *T. vulgare*, *T. spelta*, *T. macha*, *T. compactum* and *T. sphaerococcum* and proposed that these should be considered as sub-species of *T. aestivum* L. Due to lack of adequate data, he left the position of *T. vavilovi* unaltered, but from the findings of Singh *et al.* (1957) this species can also be treated as a sub-species of *T. aestivum.* Thus, all the six hexaploid wheats should be treated as groups of cultivars under a collective specific name.

Howard and Howard (1909), in their botanical classification of the Indian wheats, assigned all extra-dense-eared Indian wheats to *T. compactum.* Percival (1921), however, found that the wheats described by Howard and Howard under the name *T. compactum* were quite different from the wheats known as '*compactum*' elsewhere, and he, therefore, coined the name *sphaerococcum* for the dense-eared Indian wheats. Vavilov (1923) concurred with Percival's view; hence, the Indian dwarf wheats are now classified under *sphaerococcum.* Extensive studies on the morphological, agricultural, milling and baking qualities of *sphaerococcum* varieties have been carried out by Singh (1946, 1959). He found that *sphaerococcum* resembles *aestivum* in all essential characteristics. In crosses between *sphaerococcum* and *aestivum*, the *aestivum* type is dominant in the F_1 generation. The F_2 progenies exhibit block transference of characters of the two parents; thus, it has not been possible to transfer the round grain character of *sphaerococcum* to *aestivum.* Singh considers Ellerton's hypothesis that *sphaerococcum* is a direct mutant of *vulgare* (=*aestivum*) caused by the deletion of several loci from a chromosome as plausible, but he has stressed that alternative modes of origin, such as natural crossing of *aestivum* with a tetraploid wheat or with a species of *Aegilops*, should not be excluded from consideration without detailed study.

The earlier view that *T. compactum* is an amphidiploid of *T. monococcum* × *T. dicoccum* has been decisively disproved by McFadden and Sears (1946). The

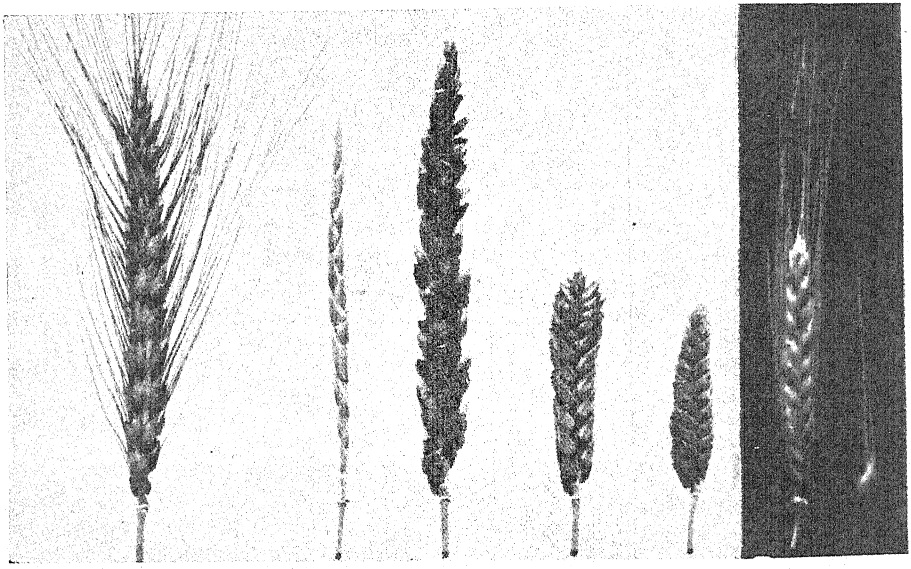

PLATE 6. Hexaploid species of *Triticum*
Left to Right: *T. aestivum*, *T. spelta*, *T. vavilovi*, *T. compactum*, *T. sphaerococcum*, *T. zhukovskyi.*

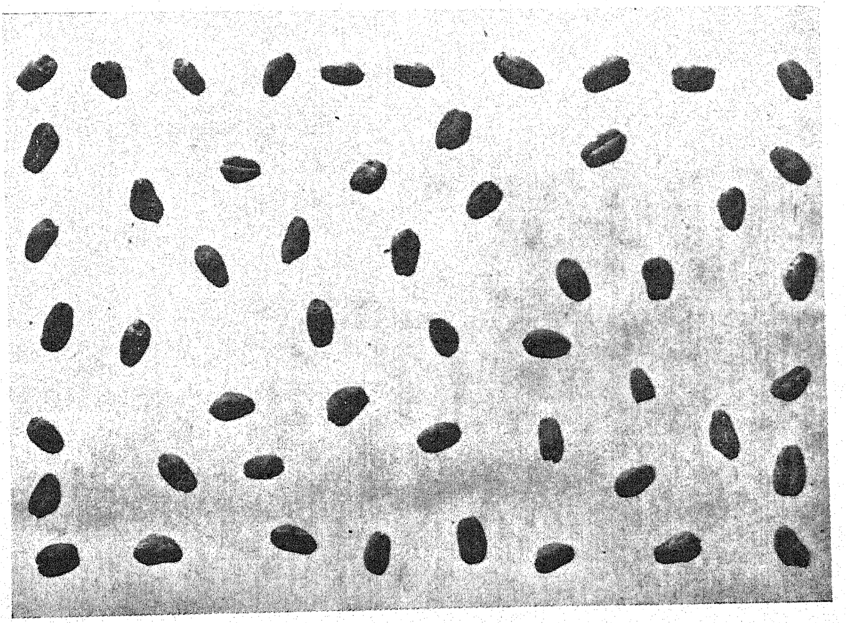

PLATE 7. Carbonized wheat grains from Mohenjo-Daro
(By courtesy of Archaeological Section, Indian Museum, Calcutta)

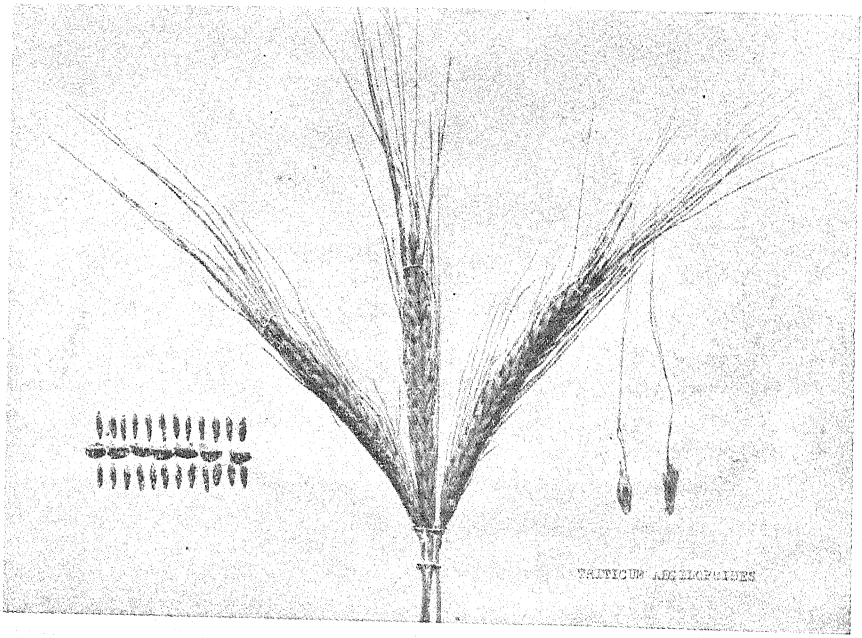

PLATE 8. *Triticum boeoticum* (≡ *T. aegilopoides*)

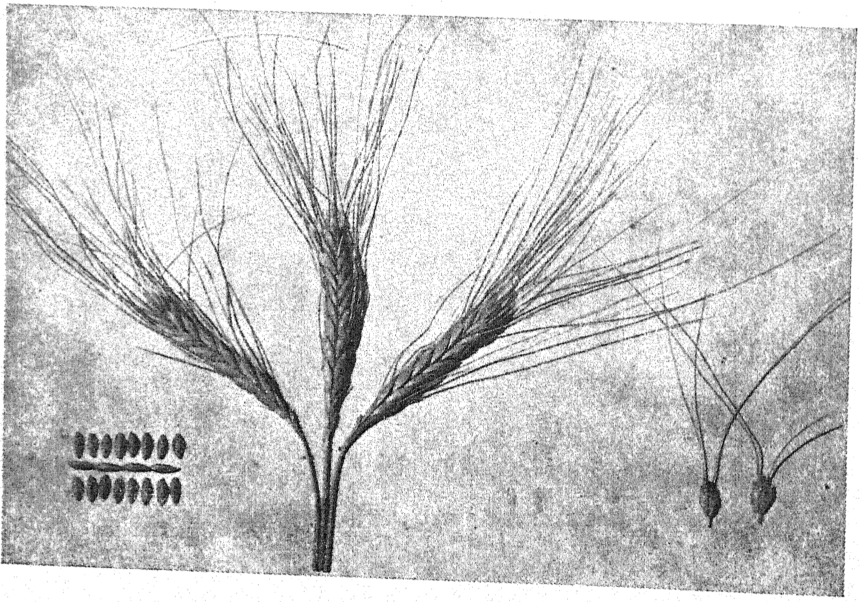

PLATE 9. *Triticum dicoccoides*

hypothesis of McFadden and Sears (1946) that the hexaploid wheats arose through the spelt form *T. spelta*, has also been criticized by Schiemann (1951) and Mac Key (1954). Among the difficulties are: (a) hulled forms of hexaploid wheats of the *spelta* type have never been found in Transcaucasia but they are endemic in the upper and middle valley of the Rhine; (b) it is easy to get hexaploid *spelta* types from the cross *T. dicoccum* × *T. compactum* or *T. aestivum* × *T. dicoccum*; and (c) the assumption of McFadden and Sears (1946) that the Lake Dwellers' compact naked wheat was a tetraploid is in disagreement with the fact that compact hexaploid wheats have been shown to occur in the oldest relics of this small group of cereals cultivated in the Lake Dwellers' Rhine area since the Neolithic age. Mac Key (1954) suggested that *T. spelta* might have had its origin from the cross *T. compactum* (*antiquorum*) × *T. dicoccum*. On the other hand, *T. vulgare speltiforme* could occur as a mutation in *T. aestivum*. Further work is no doubt needed before definite conclusions regarding the ancestral hexaploid wheat are drawn. What is of interest from the wheat breeder's point of view is that all the six species are inter-related to such an extent that they can be grouped under one collective species.

MORPHOLOGY

The morphology of the wheat plant has been exhaustively treated in Percival's monograph (1921) and by Hector (1936). The salient features are summarized below.

Roots. Seminal or primary roots belonging initially to the embryo and secondary or adventitious roots springing from the nodes of the plant within the soil or just above it are the two groups of roots of the wheat plant.

The primary root is the developed radicle. From the sides of the axis, about the level of the epiblast, a pair of lateral rootlets develop. A second pair emerges later just above the first pair. A sixth rootlet may develop at right angles to the first pair. If this develops, it appears only after others have grown to a considerable extent. This gives a maximum of five to six true seminal roots. There is a general agreement regarding the continuity of the function of these roots till the plant matures.

Adventitious roots may be the third pair of roots which develop above the second pair of seminal roots. The normal adventitious roots develop from the nodes of the main axis near the ground level. The lateral axes or tillers develop a similar series of adventitious roots. In this way a very large number of secondary roots are produced. These are somewhat thicker than the seminal roots. Later, numerous lateral rootlets appear. The extent of the root system is markedly influenced by the texture of the soil, its relative fertility and moisture supply although some evidence of varietal differences has been noted.

Stem. Stems are erect, elastic, cylindrical and in some types furrowed and either glabrous or scabrous. The nodes are five to seven in number, the average being six. Each node is contracted and solid. The whole of the lower internode and much of the upper are covered by the leaf sheaths. The lateral branches of the wheat plant, as in all grasses, are termed 'tillers'. These develop from the buds in axils of the lower leaves attached to the crowded basal nodes. When growth commences in grains sown in the field, the hypocotyl remains short but the lower part of the epicotyl lengthens into a thin erect rhizome which pushes the terminal bud upwards through the soil.

The length of the rhizome varies with the depth at which the grains are deposited. The number of tillers produced is very variable, depending on both internal and external conditions, inherent characters, seed rate, size of seed, fertility of soil and soil temperature and moisture. Three distinct types in respect of habit of growth are recognizable: erect, prostrate and intermediate. In severe wind storms and rain wheat, like other small-grained cereals, is apt to be laid. The causes of lodging are to be found in the weakness of both the straw and the root-hold. These may be inherent characteristics of the variety or may be produced by external conditions.

Leaves. The wheat plant possesses several forms of leaves, viz., (1) the scutellum, (2) the coleoptile, (3) foliage leaves, (4) prophylls of the later axils, and (5) the glumes of the inflorescences. The normal foliage leaf of wheat, as in all grasses, is divisible into two parts, the sheath and the blade. It also possesses two accessory structures, the ligule and the auricles. Near the base the sheath is entire; higher up it is split. It is generally thicker than the blade, with thin transparent margins. The surface is either glabrous or covered with deflexed hairs. The blade is long and narrow with prominent parallel veins. The first and sometimes the second leaf have a blunt and somewhat stiff tip; the tips of the other leaves are acuminate and slightly hooded. There is a tendency for the whole leaf to be slightly twisted. Attached to the junction of the blade and the sheath is a thin membrane, the ligule. It is colourless and its free margin is irregularly cut and fringed with minute hairs. Non-ligulate types are also known. The claw-like appendages, attached to the base of the leaf and loosely clasping the sheath, constitute the auricles; their tips and margins are usually thin with long unicellular hairs.

The foliage leaves are opposite in arrangement. In the buds the leaves are convolute.

Inflorescence. The inflorescence of wheat is the so-called 'ear'—a compound distichous spike, whose primary axis bears two opposite rows of lateral spikelets and a single terminal spikelet. In *T. monococcum*, the terminal spikelet is rudimentary and absent; in others it is potentially fertile. The main axis has numerous internodes with narrow base and broader apex. The whole axis has a zig-zag appearance. The spikelets are sessile and arranged alternately. The main axis is tough and does not break even when thrashed, in some of the wheats. In certain others, such as *T. monococcum*, *T. dicoccoides*, *T. dicoccum* and *T. spelta*, the axis is brittle and breaks down when the grains are ripe.

Spikelets: The spikelet consists of a shortened, jointed axis, the rachilla, carrying a variable number of alternately placed, solitary and sessile flowers. Two glumes occur at the base of each spikelet. They vary in different types, the typical glume being boat-shaped with rounded base, with the main nerve dividing it into two unequal halves; of these the outer half is the broader one. The apex of the glume may be broad with blunt extension of the midrib, or narrower with the nerve continued into an acute point; in a few this becomes a scabrid awn. The surface is either glabrous or hairy. As a rule, in a spikelet, two grains mature but three grains may form in certain varieties, and very exceptionally four.

Floret: Each flower possesses two bracts, namely, a lemma and a palea, opposite to each other, the lemma being below the palea in insertion.

Grains. The mature grain is not a seed but an indehiscent fruit with a thin-walled pericarp enclosing a single seed whose coat, the testa, is fused with the pericarp. The shape varies but it is generally more or less oval. The dorsal surface is smooth and rounded; the ventral surface has a central groove or furrow, the 'crease' of the millers. At the base of the dorsal side, a small wrinkled patch indicates the position of the embryo. The apex is clothed with short, stiff hairs, curving inwards and forming the so-called brush. The colour is either red or white.

The so-called 'cheeks' on either side of the crease may be round and plump, flat, sunken, with sharp edges or protruded.

Four structures are recognizable in the grain: (1) the grain coat, (2) the nucellar epidermis, (3) the endosperm, and (4) the embryo.

The endosperm, made up largely of starch and gluten, constitutes the greater part (82 to 86 per cent) of the grain. The percentage of gluten is highest next to the aleurone and decreases inwards.

The embryo, constituting only 6 per cent of the grain, lies at the base of the grain on the dorsal side. It consists of a short axis with the plumule at its apex and the primary root at its base. Attached to the inner side is a fleshy shield-shaped structure, the scutellum. This forms the greater portion of the embryo. On the outer side and opposite the scutellum there is a small tongue-like projection, the epiblast.

ANATOMY

Root. (A) *Primary root:* The primary root of wheat consists of three well-defined regions: (1) the epidermis; (2) the cortical zone, limited centripetally by the endodermis; and (3) the polyarch stele, limited externally by the pericycle (Fig. 2).

The epidermis consists of thin-walled cells which are elongated in their axial dimension. Many of them develop as root hairs by an extension of the outer tangential wall, usually that part of it nearest the root-tip. The cortex consists of four to eight layers of rather compact parenchymatous tissue with small intercellular spaces at the angles of the cells.

The pericycle consists of single-layered cells of almost uniform size and dimension. The protoxylem comprises a few small annular or spiral vessels, and central to them is a single large pitted metaxylem element. Small groups of phloem cells, usually two to four in number, alternate with the protoxylem strands, and between the phloem and xylem are fundamental parenchyma cells.

The lateral roots originate from cells of the pericycle layer directly outside of the phloem groups and between two adjacent protoxylem strands.

(B) *Adventitious roots:* The adventitious roots differ, in anatomy, from the seminal roots in having: (1) more persistent cortical cells which may form a two- or three-cell thick hypodermal zone; (2) development of several large metaxylem vessels instead of a single one; and (3) the presence of a correspondingly smaller amount of stellar parenchyma, which becomes lignified early in ontogeny so that it is difficult to distinguish protoxylem from parenchyma in transection.

Stem. The following are the five principal tissues which can be identified in a wheat stem (Fig. 3).

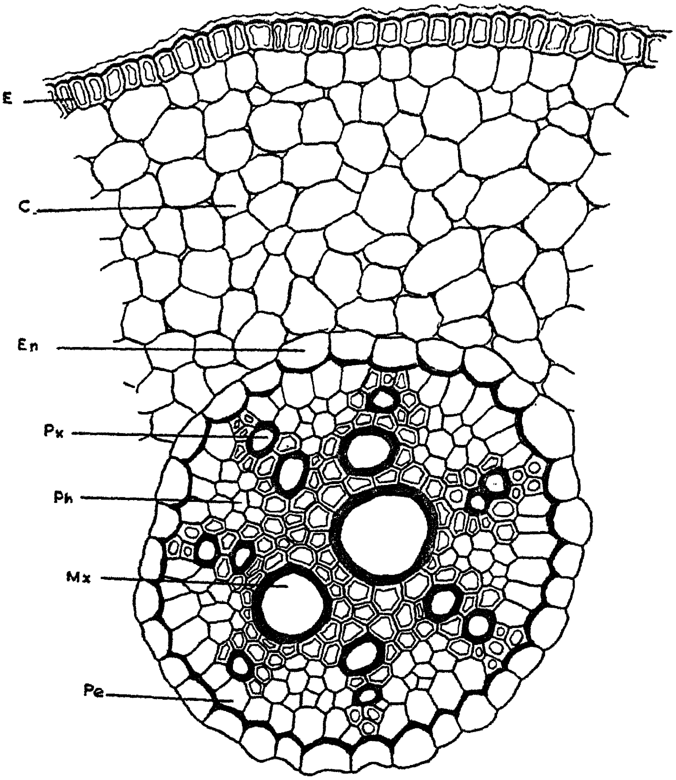

FIG. 2. Transverse section of a part of primary root of *Triticum aestivum* *C*, cortex; *E*, epidermis; *En*, endodermis; *Mx*, metaxylem; *Pe*, pericycle; *Ph*, phloem; *Px*, protoxylem.

Epidermis: The epidermis consists (apart from the guard cells of the stomata) of a few longitudinal rows of elongated and narrow cells, separated at intervals by small isodiametric cells. The stomata occur in single or double rows and are similar to those found in the leaf.

Mechanical tissue: The mechanical tissue of the hypodermal region is made up of elongated, fibrous cells with thick walls and narrow lumina, which form a continuous zone of variable thickness within the epidermis.

Chlorophyll parenchyma: This tissue occurs as parallel bands embedded in the hypodermis and consists of thin-walled cells that are circular in transection and elongated in the axial dimension. Each band touches the epidermis on its inner surface, and is in communication with the exterior via the stomata.

Fundamental parenchyma: The fundamental parenchyma extends from the zone of mechanical tissue to the central cavity. It consists of thin-walled cells that are polygonal in transection and elongated in the longitudinal dimension, with those adjacent to the mechanical tissue being longer than the centrally located ones. At the lower internodes, they may become thickened and lignified.

Vascular bundles: The vascular tissue in the internodal region consists of two rings of bundles. The outer ring consists of small bundles that alternate with

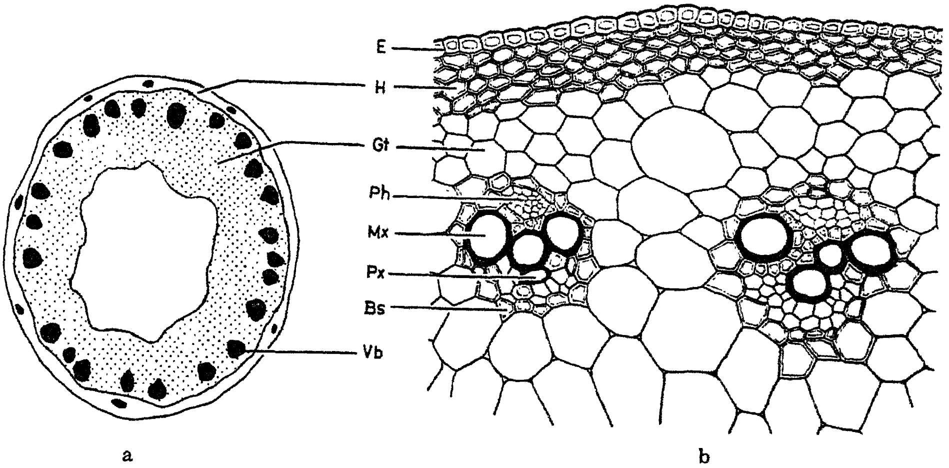

FIG. 3. Transverse section of stem of *Triticum aestivum;* (a) Semidiagrammatic outline; (b) Part of same enlarged.

Bs, bundle sheath; *E*, epidermis; *Gt*, ground tissue; *H*, hypodermis; *Mx*, metaxylem; *Ph*, phloem; *Px*, protoxylem; *Vb*, vascular bundle.

bands of chlorenchyma, while the larger bundles of the inner ring lie in the fundamental parenchyma. Each bundle is of the closed collateral type. The protoxylem consists of one or two annular or spiral vessels. The large, laterally placed metaxylem vessels are pitted and between them are several small pitted tracheids. The phloem comprises slender thin-walled sieve tubes and companion cells.

Leaf. The foliar leaf of wheat is composed of four tissues—the epidermis, the assimilating parenchyma, the strengthening tissue and the vascular bundles (Fig. 6).

Epidermis: The epidermal cells are arranged in rows which run parallel to the long axis of the blade. Some of these cells are elongated while others are approximately square in surface view. Epidermal hairs when present are of varying lengths and arise from the surface in a more or less regular arrangement (Figs. 4, 5).

The adaxial surface is somewhat ridged, while the abaxial one is nearly flat; and in the furrows of the former are single or double lines of stomata with bands of motor or bulliform cells between them. The stomatal apparatus consists of two narrow guard cells which surround the stomata and two accessory cells. The abaxial epidermis is like the adaxial with respect to the arrangement of the cells, but differs from it in the absence of ridges and motor cells. In addition, the cell walls may be somewhat thicker, the number of hairs fewer, and the stomata more commonly distributed in single rows.

Leaf parenchyma: The greater part of parenchyma consists of assimilating tissue with lenticular chloroplasts. The outer cells are somewhat elongated and regularly arranged. Within, the central tissue consists of more irregular, loosely packed cells. The true assimilating tissue, the chlorenchyma strands, is three or four layers in thickness and occurs between the vascular bundles.

Sclerenchyma: Longitudinal strands of this thick-walled mechanical tissue are located above and below the bundles and also along each margin of the leaf blade, immediately within the epidermis. In the leaf sheath the sclerenchyma is usually

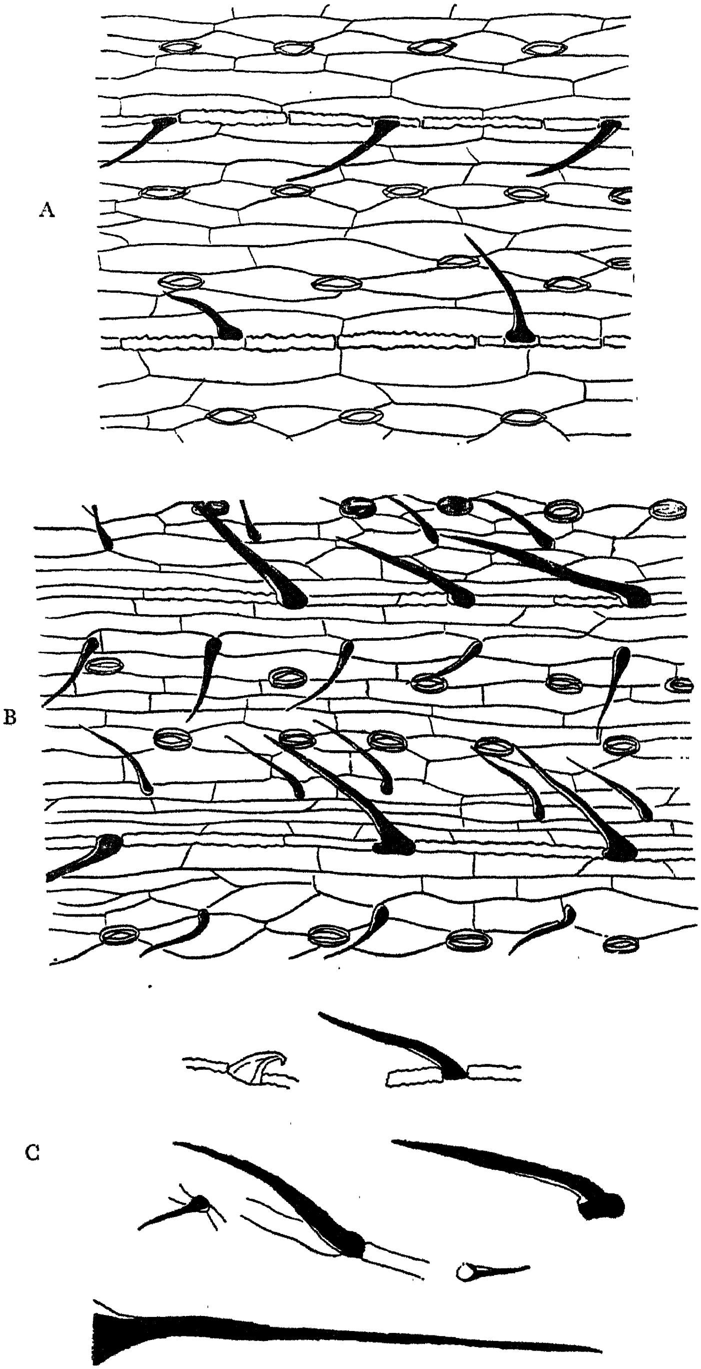

Fig. 4. Leaf epidermis. A, Upper epidermis of W.R.S. (*T. aestivum*); B, Upper epidermis of W.C. 12 (*T. aestivum*); C, Different types of hairs occurring on the leaf epidermis of *Triticum* species.
(*After* Pal *et al.*, 1952; by courtesy of Editor, *Indian J. Genet.*)

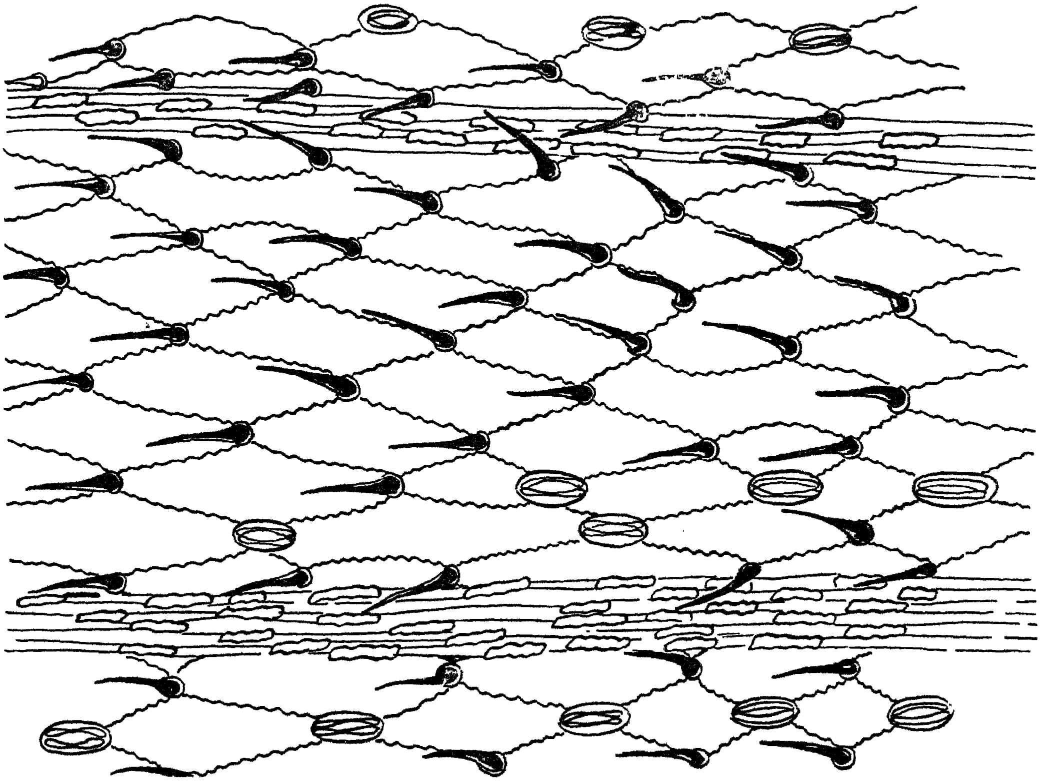

FIG. 5. Leaf sheath epidermis of N. P. 114 (*T. aestivum*)
(*After* Pal *et al.*, 1952; by courtesy of Editor, *Indian J. Genet.*)

restricted to zones adjacent to the abaxial surface, the amount increasing toward the node.

Vascular bundles: Vascular bundles of two sizes extend parallel with the long axis of the lamina, and small transverse veins interconnect the longitudinal strands which may occasionally branch or anastamose towards the apex of the blade. The bundles are of collateral type. The larger ones have one or more annular or spiral elements and two large pitted vessels. The small longitudinal bundles have no large vessels. The transverse bundles are characterized by xylem consisting of short tracheids. Phloem is present in all cases but in the case of transverse bundles it is limited to a few elongated parenchymatous cells.

The reader is referred to Hector (1936) for further details concerning the anatomy of the root, stem and leaf of wheat.

EMBRYOLOGY

Microsporogenesis. In each angle of the anther, an archesporial cell is formed, which by periclinal division forms the parietal and the sporogenous cells. Radial divisions of the parietal cell produce four cells, and these, with the adjoining ones, form a layer which encloses the sporogenous cell. Subsequently, three concentric

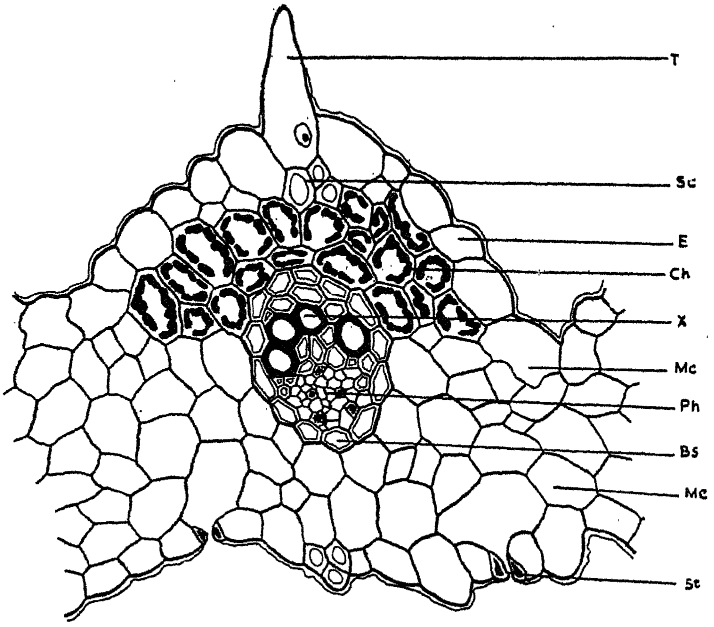

FIG. 6 Transverse section of a part of leaf of *Triticum aestivum*
Bs, bundle sheath; *Ch*, chloroplast; *E*, epidermis; *Mc*, motor cell; *Me*, mesophyll cell; Ph, phloem; *Sc*, sclerenchyma; St, stomata; *T*, trichome; *X*, xylem.

layers are formed by successive periclinal divisions of the cells of the parietal layer, the inner one becoming the tapetum and the outer the endothecium. The pollen mother cells form a single layer lining the anther chamber. Finally, meiotic divisions result in the formation of tetrads of microspores. The sporads are usually isobilateral and the pollen grains are trinucleate at the time of anthesis.

Megasporogenesis. Successive divisions of a wedge-shaped, hypodermal, archesporial cell result in the formation of a linear tetrad of megaspores. The three outer cells disintegrate and the innermost chalazal one enlarges greatly and becomes the functional megaspore. The megagametophyte becomes eight-nucleate by three divisions of the megaspore nucleus. The two synergids and the egg cell occupy the micropylar end. The polar nuclei fuse before gametic union. The three antipodal cells at the chalazal end increase in size and divide to form six to ten cells according to Percival (1921), though 36 or more may be formed according to Körnicke (1896).

Fertilization. Before germination the pollen grain is trinucleate, having one tube nucleus and two male gametes. Pollen tubes appear within one and a half to two hours after pollination. On reaching the cavity of the ovary, the tube passes to the micropyle and comes into contact with the egg apparatus. In the pollen tube the male nuclei lead while the tube nucleus lags behind. The first of the two nuclei fuses with the egg nucleus to form the zygote. Double fertilization occurs between 24 and 48 hours after pollination (Brenchley, 1909).

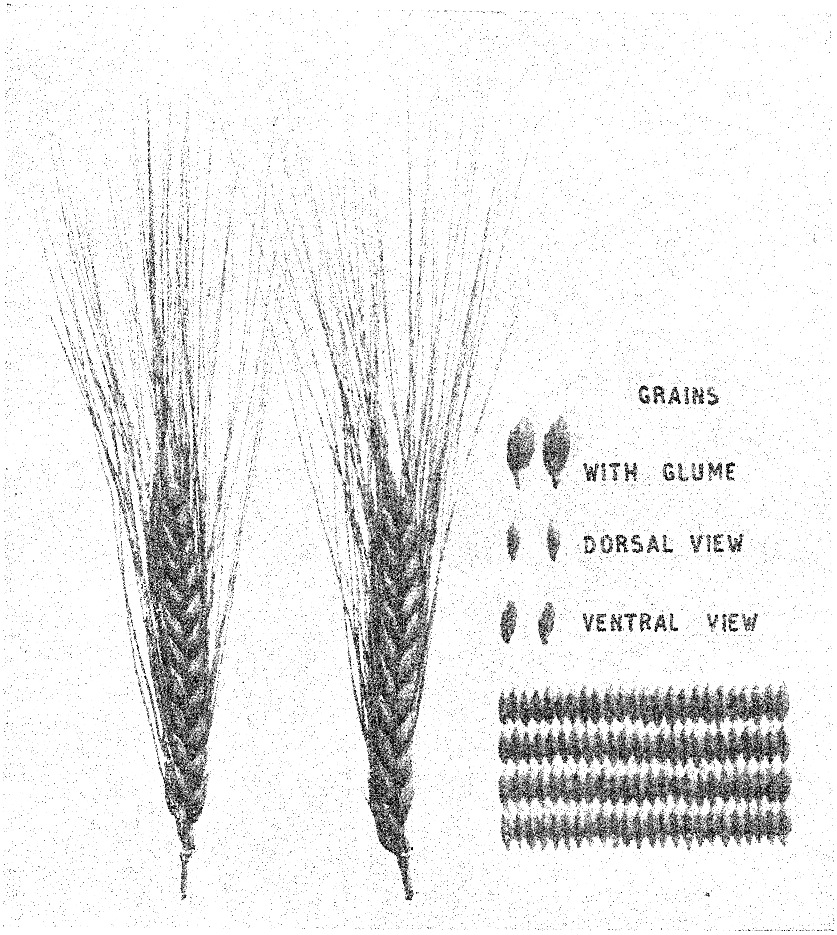

PLATE 10. *Triticum dicoccum*

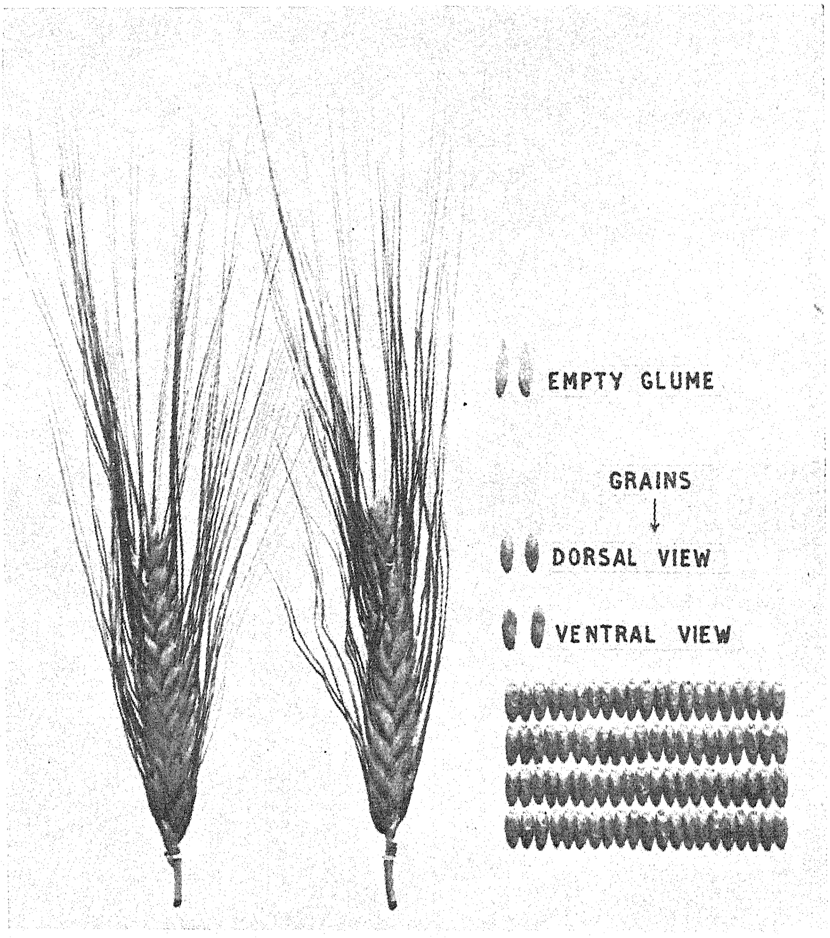

PLATE 11. *Triticum durum*

Development of the embryo. The first division of the embryo is transverse; the large basal cell does not undergo any further division and functions as the suspensor, and the upper cell, after undergoing two divisions, forms a four-celled proembryo. Subsequent divisions in all planes result in a marked increase in the size of the embryo; and in a few days, the dermatogen can be distinguished surrounding a central body of cells. At this stage the embryo is club-shaped with a narrow elongated base. Further divisions and differentiation leads to the formation of scutellum, coleoptile, initials of foliage leaves, epiblast, etc. (Fig. 7).

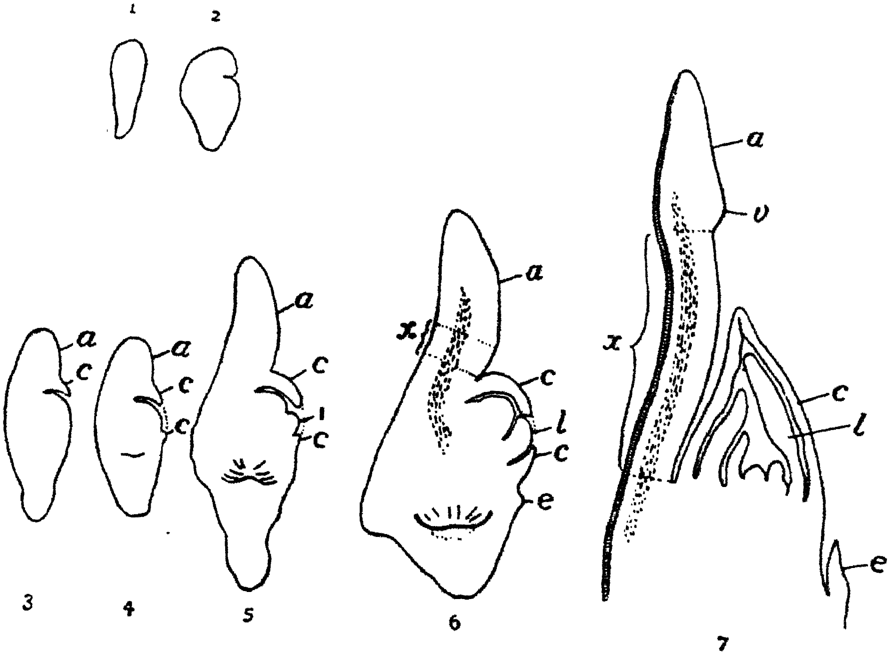

FIG. 7. Development and differentiation of the wheat embryo

a, upper portion of scutellum (blade of the cotyledon); *c*, coleoptile; *e*, epiblast; *l*, first foliage leaf; *v*, 'ventral' scale (ligule of the cotyledon); *x*, intercalary zone of scutellum (sheath of the cotyledon).

(*Redrawn after* Percival, 1921)

CLASSIFICATION

Linnaeus, in the first edition of his *Species Plantarum* (1753), classified the then known cultivated wheats under five species. Later, he added a sixth one. Thereafter, the number of species recognized has varied from a minimum of three to a maximum of 20. Percival (1921) enumerated two species and 12 'races', which might with equal justice be designated 'Cultivated Species'. Several additional species have since been described. According to the nomenclature proposed by Schiemann (1949), 13 valid species can be recognized under the genus *Triticum* (*see* Table III). The species *T. pyramidale* has been included by her under *T. durum*, following Flaksberger and Vavilov. Again, *T. compactum* has been included under *T. aestivum.* Certain other new forms which have been given specific rank by Nevski, such as *T.*

armeniacum (Stol.) Nev. and *T. volgense* (Flaksb.) Nev., are included by Schiemann, following Stoletore and Flaksberger, as varieties of *T. dicoccum.*

Classification of the genus *Triticum*

(After Elizabeth Schiemann, 1949)

EINKORN SERIES

1. *T. boeoticum* Boiss. emend. Schiem.
   =*T. aegilopoides* (Link) Bal. with the sub-species *T. aegilopoides* (Link) Schiem. and *T. thaoudar* (Reuter) Schiem.
2. *T. monococcum* L.

EMMER SERIES

3. *T. dicoccoides* Körn.
4. *T. timopheevi* Zhuk.
5. *T. dicoccum* Schübl.
6. *T. durum* Desf.
7. *T. percivalli* Hubb. (=*T. orientale* Perc.)
8. *T. turgidum* L.
9. *T. polonicum* L.
10. *T. carthlicum* Nev. (=*T. persicum* Vav.)

DINKEL SERIES

11. *T. spelta* L.
12. *T. macha* Dek. et Men.
13. *T. aestivum* L. (Linnaeus, in 1753, distinguished six species of wheat among which were *T. aestivum* and *T. hybernum.* Villiers, in 1787, referred the then known wheats to seven species. Later, Host combined these two binomials of Linnaeus under one species, namely, *T. vulgare.* However, Schiemann, in 1949, restored the Linnaean combination on the basis of its priority and this change has been accepted by the International Committee on Botanical Nomenclature in 1952. The correct botanical designation of the common bread wheat is, therefore, *Triticum aestivum* L.).

Jakubziner (1958) has presented a table of the species of wheat recognized by him and their habitats. This list includes 21 species but many of the new species mentioned are only new names for already known species. Among the new species described by Jakubziner from Russia are *T. urartu* Tum. ($2n=14$), *T. ararticum* Men., *T. paleocolchicum* Men. ($2n=28$) and *T. zhukovskyi* Men. et Er. ($2n=42$).

DESCRIPTION OF WHEAT SPECIES

The important distinguishing characteristics of the various species and their geographical distribution, as listed by Percival (1921) and Hector (1936), are summarized below.

1. **Triticum aegilopoides** Bal. Wild Small Spelt (Plate 8)

Coleoptile: Usually purple, two-nerved.

Young shoots: Erect, with broad leaves or prostrate with narrow leaves; leaves more or less finely hairy with longer hairs on the longitudinal ridges.

Stem: Slender, erect, solid or hollow with thick walls; nodes with white deflexed hairs.

Ear: Bearded and compressed; narrow across the face, broad across the two-rowed profile.

Rachis: Fragile, disarticulating from above downwards, smooth; fringed along the margins and with a tuft of whitish hairs at each node in front of the spikelet.

Spikelets: Terminal spikelet abortive; others two-flowered, the lower fertile, the upper usually sterile.

Glumes: Tough, long, narrow, keeled throughout, with stout acute tooth often pointing outwards; prominent lateral nerve ending in secondary tooth.

Lemmas: Scabridly awned, the awn of the upper flowers tending to reduction.

Palea: Entire, splitting longitudinally at maturity.

Grain: Small, pointed at both ends, compressed, furrow indistinct, flinty; apical brush scanty to abundant; olive-yellow, pink, red to greenish in colour.

T. aegilopoides is widely distributed in parts of the Balkans, Asia Minor, the Crimea, Transcaucasia, Palestine and Syria to the borders of Persia. The Mediterranean forms are said by Vavilov to be larger than the Asian forms. There is also marked parallelism between the wild einkorns and the wild emmers.

2. **Triticum monococcum** L. EINKORN OR SMALL SPELT

Coleoptile: Two-nerved.

Young shoots: Prostrate, semi-erect to erect; leaves narrow; hairs few and very short.

Stem: Slender, erect, usually hollow with thin walls; nodes with deflexed hairs.

Ear: Bearded and compressed, much narrower across the face than the two-rowed profile; denser than *aegilopoides.*

Rachis: Flattened, fragile, glabrous or at times fringed with tufts of hair as in *aegilopoides.*

Spikelets: Terminal minute, infertile; others three-flowered but one- or two-grained only.

Glumes: Tough, long, narrow, keeled throughout with stout, acute tooth, straight or turning inwards; prominent lateral nerve ending in secondary tooth.

Lemmas: Longer than the glumes with terminal sinus and straight scabrid awn; awn short or absent on upper florets.

Palea: Entire, but splitting at maturity.

Grain: As in *aegilopoides* but shorter.

Small spelt has been cultivated since the pre-historic time in Western Europe and parts of Asia Minor, but is now of very minor economic importance.

3. **Triticum dicoccoides** Körn. WILD EMMER (Plate 9)

Coleoptile: Usually purple, four-nerved.

Young shoots: Prostrate; leaves narrow with short relatively coarse hairs or, according to Percival, fine soft hair.

Stem: Slender, solid or (according to Percival) hollow with thick walls; nodes with deflexed hairs.

Ear: Bearded, compressed, much narrower across the face than the two-rowed profile; lax.

Rachis: Fragile, disarticulating above the spikelet, flattened, smooth, shining with conspicuous lateral fringe of long white, yellow or dark brown hairs.

Spikelets: Terminal, usually sterile; others three-flowered but one- (or two-) grained.

Glumes: Tough, long, narrow, glabrous or with silky hairs, with strong scabrid keel having blunt or acute tooth, straight or curving inwards or outwards; prominent nerve ending in secondary tooth.

Lemmas: Somewhat shorter than glumes, slightly divided at apex with strong scabrid, slightly dorsal awns.

Palea: Divided at tip, not splitting at maturity.

Grain: Very long, narrow, pointed at both ends, triangular in outline, apical brush of long, whitish hairs.

T. dicoccoides was first noted by Körnicke in 1873 as a portion of an ear mounted with a herbarium specimen of *Hordeum spontaneum*. Aaronsohn rediscovered the plant at Rosh Pinar in 1906. It appears to be widely distributed in Palestine, Syria, Armenia, Transcaucasia and Western Persia; and the evidence that it is a truly wild species is now convincing.

It is of interest to note that Love and Craig (1919) produced a synthetic type morphologically similar to *T. dicoccoides* from a cross between *T. vulgare* (=*aestivum*) (Early Red Chief) and *T. durum* (macaroni). Further tests (1924) indicated that the synthetic form behaves genetically as does the wild form.

4. **Triticum dicoccum** Schübl. CULTIVATED EMMER (Plate 10)

Coleoptile: Four- to six-nerved in Indo-Abyssinian types; two-nerved in European types.

Young shoots: Usually erect, with short hairs of nearly uniform length on the young leaves; auricles pinkish, fringed in European forms, more or less glabrous in Indo-Abyssinian forms.

Stem: Somewhat slender, solid or hollow with thick walls.

Ear: Bearded, compressed, narrower across the face than the profile.

Rachis: Fragile or tough, disarticulating above the spikelets, rarely tending to cohere; flattened, smooth, more or less hairy along the margins, each segment narrow below and widening considerably above.

Spikelets: All more or less fertile, three- to four-flowered, setting typically two grains.

Glumes: Long, narrow, strongly keeled with apical tooth acute and curved or short and blunt; outer face flat.

Lemmas: With three-angled awns.

Palea: Ovate-lanceolate with narrow bifid apex.

Grain: Long, narrow, pointed at both ends, ventral side flat to slightly concave and with narrow furrow; flinty to semi-flinty.

The species, as described by Percival, is a complex one including : (1) *T. dicoccum* Schrk., (2) Indo-Abyssinian forms with a tough rachis, and (3) *T. persicum* Vav.

Emmer wheat is now restricted in cultivation to the more backward and primitive districts. Formerly it had a much wider distribution. There is, for example, evidence of its cultivation in the neolithic times in Switzerland (Heer, *see* Percival, 1921), and in Denmark, Germany and Bohemia (Schultz, 1915). That it was widely cultivated in ancient Egypt is now accepted (*see* Percival, 1921), and according to Hrozny (*see* Percival) it was the chief cereal cultivated in Babylonia. Its gradual replacement by *durum* and *vulgare* wheats took place in the Graeco-Roman period.

5. **Triticum orientale** Perc. KHORASAN WHEAT

Coleoptile: Two-nerved.

Young shoots: Erect, with very narrow pubescent leaves.

Stem: Thin, of medium height, solid or hollow with thick walls.

Ear: Bearded, very lax and almost square.

Rachis: Tough with fringed margins; internodes narrow and wedge-shaped.

Spikelets: All fertile, three-flowered, two- to three-grained.

Glumes: Long, narrow, keeled to the base, with blunt apical tooth, lateral nerve prominent; white and pubescent.

Lemmas: With scabrid, usually deciduous awns.

Grain: Very long, narrow and flinty.

Percival reports the species as a small distinct race cultivated on irrigated land in Persia. It is regarded as a form of *durum* by Jakubziner (1932).

6. **Triticum durum** Desf. DURUM OR MACARONI WHEAT (Plate 11)

Coleoptile: Two-nerved.

Young shoots: Erect, quite glabrous or nearly so.

Stem: Tall, solid or hollow with thick walls.

Ear: Bearded, square or narrower across the face than the profile.

Rachis: Tough or disarticulating somewhat, especially towards the base, margins fringed with frontal tuft of hairs at the spikelets.

Spikelets: Somewhat long and narrow, five- to seven-flowered, two- to four-grained.

Glumes: Long and narrow, outer face somewhat flattened, glabrous or hairy, with prominent, curved keel from base to tip, and strong, inwardly curved apical tooth.

Lemmas: Nine- to 15-nerved, thin, pale and rounded on the back; the awns long, almost smooth at the base, diverging slightly; those of the upper lemmas of a spikelet usually shorter.

Grain: Long, narrow, flinty, more or less pointed at both ends; dorsal ridge prominent; crease shallow with sloping sides; cross section somewhat triangular.

The *durums* are the only group of 28-chromosome wheats which have survived in extensive cultivation to the present day. From an economic standpoint, owing to their drought resistance, coupled with their resistance to rust and other fungi and the inherent 'strength' of the grain, the *durum* wheats are, especially in the warmer and somewhat arid districts, of equal importance to the *aestivum* wheats. Their characters have recently been studied in great detail by the Russian investigators.

7. **Triticum polonicum** L. POLISH WHEAT

Coleoptile: Two-nerved.

Young shoots: Erect; young leaves blue-green and glabrous.

Stem: Tall, solid or hollow with thick walls.

Ear: Bearded, somewhat square, lax to medium.

Rachis: Somewhat fragile; flattened and smooth; margins fringed; frontal tuft of hair to each spikelet.

Spikelets: Bearded; large and flattened; four- to five-flowered, one to two- or three-grained.

Glumes: As long as, or longer than the spikelet, lanceolate and narrow, keeled throughout, the keel fringed and ending in a short tooth; secondary tooth small or absent.

Lemmas: Boat-shaped, rounded on the back, 15- to 17-nerved, edges fringed with short hairs; the two lowest lemmas distinctly awned, the upper shortly awned or not awned.

Grain: Very long, narrow, yellowish white or pale red, flinty; somewhat triangular.

Polish wheat appears to be of comparatively recent origin but as it possesses no characteristics which are not found in a higher degree in the *durums*, its cultivation has always been limited.

8. **Triticum turgidum** L. RIVET OR CONE WHEAT

Coleoptile: Two-nerved.

Young shoots: Erect or prostrate; with short narrow leaves usually dark bluish green, covered with soft hairs of nearly uniform length.

Stem: Tall, solid or hollow with thick walls.

Ear: Usually bearded; square or narrower across the face than the two-rowed profile; often pendulous.

Rachis: Tough; margins densely fringed with white hairs, similar frontal tuft before each spikelet.

Spikelets: About as long as broad; five- to seven-flowered, three- to five-grained.

Glumes: Tough, short and broad; the outer face convex, five- to seven-nerved, prominently keeled throughout, the keel ending in a stout, usually acute and curved tooth; prominent lateral nerve often present, sometimes ending in a short secondary tooth.

Lemmas: Thin and fragile; oval and boat-shaped with 9 to 15 fine nerves; awns stout, triangular in section, scabrid and sometimes deciduous.

Grain: Large, plump and somewhat short; mealy; apex truncate; dorsal crest behind embryo high; furrow shallow, with rounded cheeks.

The Rivet wheats are high-yielding but the flour is 'weak'. They are intensively cultivated in certain localities, but are not widely distributed.

9. **Triticum pyramidale** Perc. EGYPTIAN CONE WHEAT

Coleoptile: Two-nerved.

Young shoots: Erect, with soft hairs of nearly uniform length on the leaves [this velvety pubescence is said by Jakubziner (1932) not to be typical]; older leaves yellowish green.

Stem: Short, solid or hollow with thick walls.

Ear: Bearded, short, dense, tending to taper towards the apex, narrower across the face than the two-rowed profile.

Rachis: Tough; margin fringed with white hairs; frontal tuft before each spikelet.

Spikelets: More or less square; three- to four-grained.

Glumes: Tough, strongly keeled throughout, apical tooth long and acute, or short and blunt.

Lemmas: With slender awn, scabrid to the base.

Grain: Usually white; short, narrow, somewhat pointed at apex; dorsal hump prominent.

Egyptian Cone wheat is a small group, first described by Percival from Egypt. Jakubziner (1932) considers that it is really a *durum.*

10. **T. timopheevi** Zhuk. (Plate 12)

Coleoptile: Two-nerved.

Young shoots: More or less prostrate; leaf sheaths with long, white, dense hairs; similar but less dense hairs on the leaves.

Ear: Bearded, compact and broad; wider across the face than the profile.

Rachis: Somewhat brittle at maturity; pubescent, with thin short hairs.

Glumes: Somewhat short; keeled, no wing-like appendages.

Lemmas: Thin, membranous and awned; awns soft, thin and short.

Palea: Tending to split longitudinally at maturity.

Grain: Small and somewhat pointed.

It is a wild species found in high mountainous regions in Georgia and is markedly resistant to rust, smut and mildew.

11. **Triticum aestivum** L. BREAD WHEAT (Plate 13)

Coleoptile: Two-nerved.

Young shoots: Erect, semi-erect to prostrate; young leaves with long hairs on the summit of the longitudinal ridges with shorter hairs often present on the flanks.

Stem: Variable in height; hollow with thin walls, occasionally with solid upper internodes.

Ear: Bearded to beardless; variable in density; square or broader across the face than the two-rowed profile.

Rachis: Tough, fringed with short hairs on the margins; a few hairs at the base of each spikelet.

Spikelets: About as long as broad; five- to nine-flowered, ripening four to five grains towards the centre, usually fewer at base and apex.

Glumes: Loose and broad, the outer face convex; usually keeled in upper half only and then with rounded base, rarely keeled throughout; apical tooth in bearded forms short and acute, or prolonged into an awn (1 to 4 cm. long); in beardless forms usually short and blunt.

Lemmas: Thin, pale, rounded on back with seven to eleven nerves; awns when present, scabrid, triquetrous and persistent, sometimes short, stout and brittle, usually straight or slightly curved, very rarely twisted or bent.

Grain: Varied, usually plump with bluntish apex; crease shallow, cheeks convex and plump; dorsal side rounded without hump or ridge; flinty to mealy.

The bread wheats are very variable, and include a vast assemblage of varieties which may be due to a hybrid origin.

12. **Triticum compactum** Host

Coleoptile: Two-nerved, pinkish or colourless.

Young shoots: Usually erect, at times semi-erect to prostrate; with yellowish-green or blue-green leaves, usually with hairs as in *aestivum.*

Stem: Erect, stiff, generally hollow with thin walls, very rarely solid.

Ear: Bearded or beardless; short and dense; oval or oblong, at times ' clubbed ', square in section.

Rachis: Tough; fringed with hairs along the margins and across upper part of each notch below the spikelet.

Spikelets: Broad and short; six- to seven-flowered, three- to five-grained.

Glumes: As in *T. aestivum.*

Lemmas: Inflated, with scabrid, sometimes widely diverging awns in bearded types.

Grain: Small, oval and narrow towards the apex and plump; crease shallow, with plump cheeks; dorsal side sometimes with prominent hump; mealy to occasionally flinty.

This ancient species is cultivated only to a limited extent.

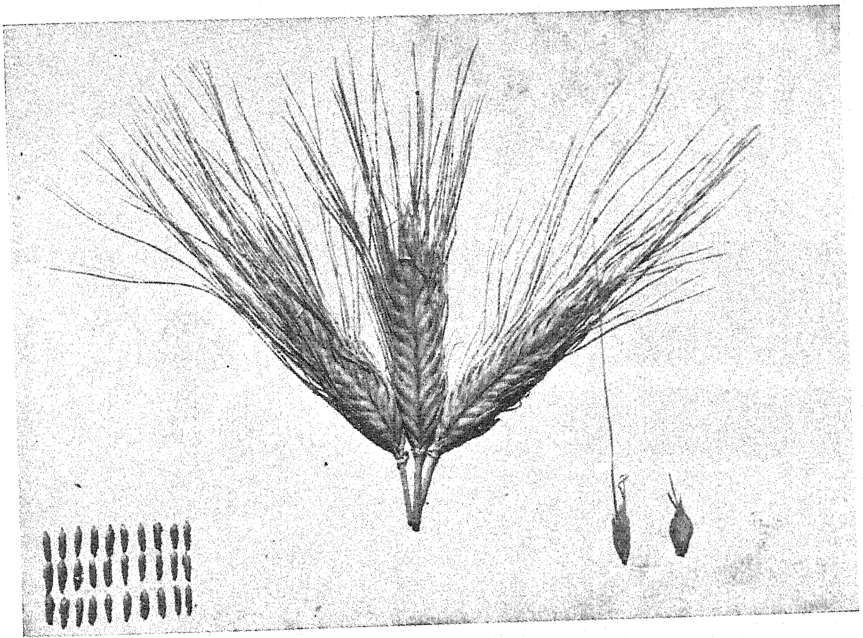

PLATE 12. *Triticum timopheevi*

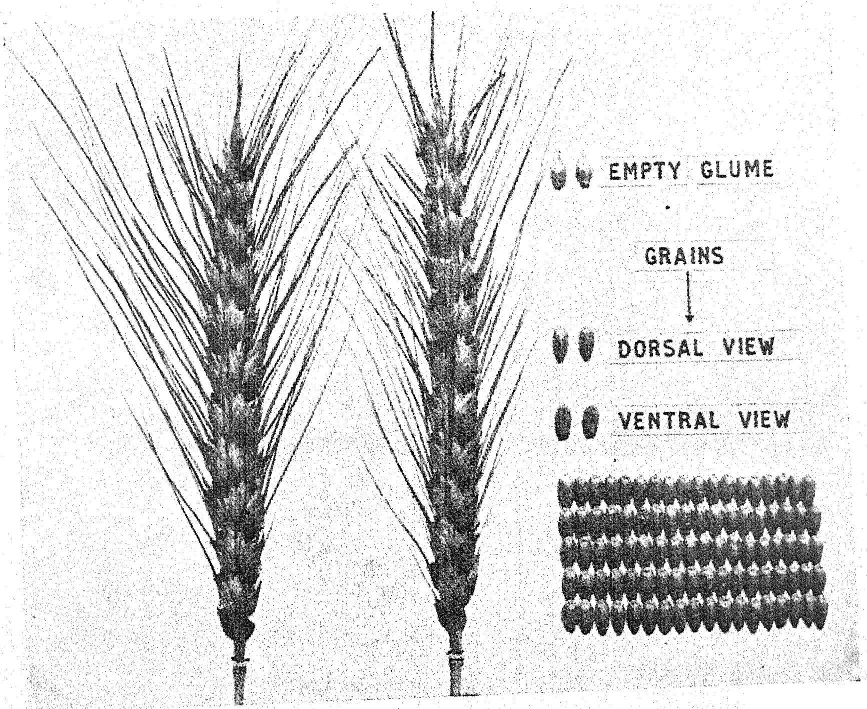

PLATE 13. *Triticum aestivum*

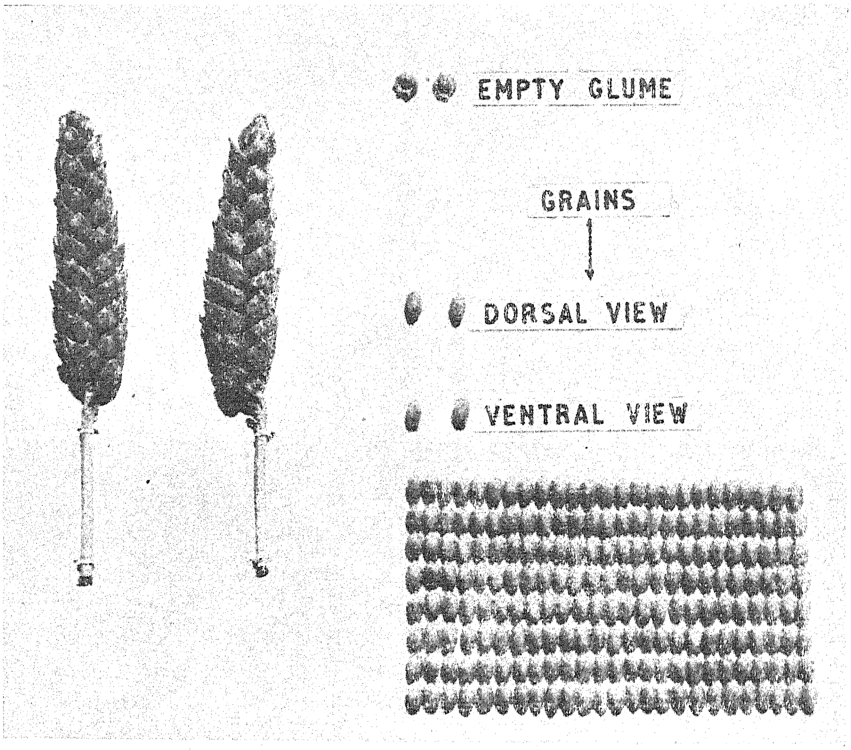

PLATE 14. *Triticum sphaerococcum*

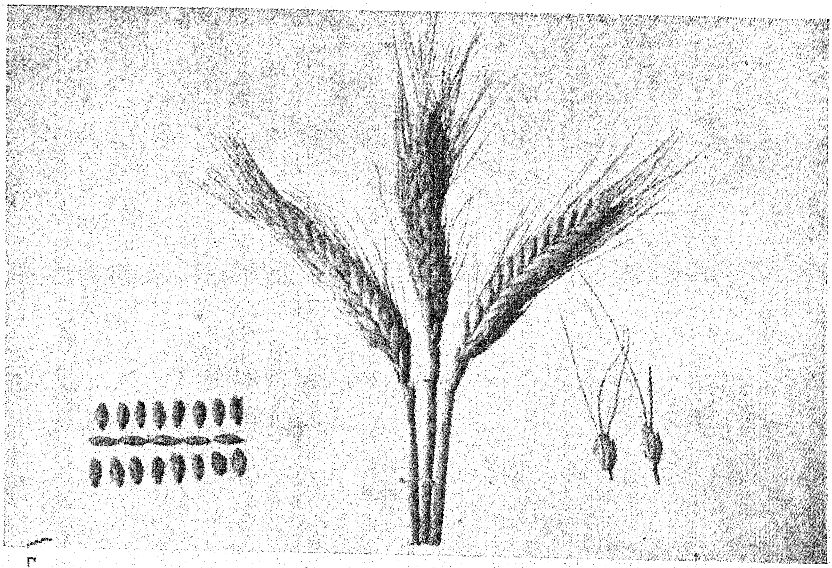

PLATE 15. *Triticum macha*

13. **Triticum sphaerococcum** Perc. INDIAN DWARF WHEAT (Plate 14)

Coleoptile: Two-nerved.

Young shoots: Erect; leaves as in *T. aestivum.*

Stem: Very short, stiff, erect and hollow.

Ear: Bearded or beardless, less dense than *T. compactum*, stiff and erect.

Rachis: Tough; margins fringed with white hairs extending along the front below each spikelet.

Spikelets: More or less square; six- to seven-flowered; four- to five-grained.

Lemmas: Broad and short, inflated, usually keeled above; apical tooth strong, curved and scabrid.

Grain: Very short, somewhat truncate to angular; flinty.

This wheat, first separated from *T. compactum* by Percival, is grown to a very limited extent in Madhya Pradesh, Uttar Pradesh and the Punjab in India. It is also grown in Persia.

14. **Triticum spelta** L. LARGE SPELT

Coleoptile: Two-nerved.

Young shoots: Erect or prostrate; with dark-green leaves, slightly hairy as in *T. aestivam.*

Stem: Stout and hollow with thin walls.

Ear: Bearded or beardless; relatively long and lax, more or less square.

Rachis: Fragile, disarticulating below the spikelets; broad and stout; convex on one side, flat or concave on the other; margins more or less hairy with very small or no frontal tuft of hairs.

Spikelets: Narrow and oval, convex in section; three- to four-flowered; two- to three-grained, except the upper spikelets which usually ripen one grain.

Glumes: Loose, with broad truncate apex and parallel nerves; keel prominent throughout, ending in short, blunt apical tooth; strong lateral nerve ending in blunt projection some distance from the apical tooth.

Lemmas: Boat-shaped, thin, 9- to 11-nerved; awn, a short claw-like projection or a true stiff scabrid awn.

Grain: Long, somewhat pointed at both ends; ventral surface flattened or hollow; shallow crease; section slightly angular, usually flinty.

Spelt wheat is generally believed to be of comparatively recent origin. In Europe, it is found mainly in two centres—South-western Germany where it is confined to the mountain ranges of the North-western Alps, the Vosges, the Black Forest and the Swabian Alps; and the Asturian province of Spain, where it occurs in the Cantabrian mountains. Its cultivation elsewhere is much scattered and till recently neither true spelt nor any allied form was known in the East. Flaksberger accordingly suggested that spelt was derived locally from *T. vulgare* (=*aestivum*) at a comparatively recent epoch. On the other hand, Percival (1921) believed that it was a segregate from a hybrid of a wheat of the emmer group with *Aegilops cylindrica*. Either supposition might be correct. However, the discovery of closely allied spelt forms in Asia (Dekaprelevich and Menabde, 1932) alters the situation, and tends to support the theory of Vavilov that all 42-chromosome wheats are of Asian origin.

15. **Triticum macha** Dek. et Men. 'MAKHA' WHEAT (Plate 15)

Coleoptile: Two-nerved.

Young shoots: Prostrate to spreading; narrow-leaved, purplish to green; older leaves also narrow but dark green, glabrous (small spines) or with sparse hairs; auricles green or purple.

Stem: About 100 cm. long; hollow throughout; nodes slightly to strongly pubescent.

Ear: Semi-bearded; long and lax to comparatively dense.

Rachis: Fragile, generally disarticulating above the spikelet as in *T. dicoccum*; broad and distinctly convex on one side, concave on the other.

Spikelets: Three- to four-flowered, ripening usually two grains, short to long and broad; often densely pubescent at the base and sometimes above, especially on the ribs.

Glumes: Varying from 'spatulate' with broad shoulder to lanceolate with no shoulder; several-nerved and usually prominent, with one lateral nerve marked and nearly always ending in a second tooth; apical tooth obtuse or acute, slightly curved, incurved or hooked.

Grain: Semi-flinty and red in colour; ventral side flat or with depression; crease broad and deep; dorsal side often wrinkled, with longitudinal furrows due to pressure of the nerves of the glume.

This species, described by Dekaprelevich and Menabde (1932), is common in W. Georgia. According to these authors, it is fairly close to, nevertheless distinct from *T. spelta*. The presence of such wheats in Georgia, many of them 'intermediate' between *T. spelta* and *T. aestivum*, was regarded by them as further proof of the origin of all 42-chromosome types in South-west Asia. They were inclined to state that *T. macha* is the main primary group and that *T. spelta* is a secondary monomorphous group derived from *T. macha*, probably at a comparatively recent epoch.

16. **Triticum zhukovskyi** Men. et Er. (Plate 6)

Menabde and Eritzan described in 1957 a hexaploid ($2n=42$) *Triticum* species found in Western Georgia in the same habitat as the tetraploid *T. timopheevi* and the diploid *T. monococcum* and named it *T. zhukovskyi*. This new species resembles *T. timopheevi* very closely in ear morphology, growth characteristics and disease resistance. On the basis of the morphological traits and distribution data, it has been suggested that *T. zhukovskyi* might have arisen as an amphiploid from the cross *T. timopheevi* × *T. monococcum* (Bowden, 1959). *T. zhukovskyi* bears a close resemblance to *T. timopheevi* in most plant characters and particularly in hairiness. The hairs in both *T. timopheevi* and *T. zhukovskyi* are long, thin and unicellular. Artificial inoculation of seedlings of *T. timopheevi* and *T. zhukovskyi* with many races of *Puccinia graminis* var. *tritici* and *Puccinia recondita* showed that they were both highly resistant. The outer glume of *T. zhukovskyi* has a notched shoulder as in *T. monococcum* and not a square one as in *Ae. squarrosa.*

CLASSIFICATION OF AGRICULTURAL VARIETIES

All these species fall into three natural groups based on the chromosome number. They are the Einkorns comprising the diploid species, the emmers comprising the tetraploid species and the Dinkel series comprising the hexaploid species.

A broad classification of this kind, however, is of comparatively limited use in such a widely cultivated crop as wheat. Here the problem is more to recognize the particular superior genotypes from among the millions of hereditary types existent within the cultivated species. The need for a classification in depth was recognized quite early by wheat workers in different countries. The earliest of such attempts resulted in the recognition of a number of botanical varieties within each species, the most comprehensive system being the one formulated by Körnicke and Werner. These workers recognized botanical varieties mainly based on ear and grain characters and designated with latin names, such as *graecum, rubrum, ferrugineum* and *lutcum.* Even this, however, was found to be inadequate to cover the wide range of agronomically important variation present in the cultivated types and the need for going deeper was soon recognized. As a result of their close acquaintance with the crop in the field, the Howards in India and Percival in England felt the imperative necessity of recognizing what they called 'types' or 'forms' within the botanical varieties of Körnicke and Werner (1885). It was Vavilov (1923), however, who gave the first concrete definition of race or type as "the smallest unit including individuals indistinguishable from each other morphologically and physiologically", although he did not carry this recognition to its logical conclusion in his grouping of the soft wheats into 'Ligulate' and 'Eligulate' with further sub-divisions based on the nature of the awns. Clark *et al.* (1922), working in the U.S.A., published extensive descriptions of varieties under cultivation, based mostly on ear and grain characters.

In India, Howard and Howard (1909) classified and described wheat varieties and their types grown in India on a provincewise basis. They critically reviewed the schemes proposed by earlier workers and concluded that the same were not completely satisfactory. They drew up a new scheme which took into account both morphological and agronomical characters, such as: (1) the tone of the colour of the chaff, (2) the erectness of ear, (3) the straw characters (length, strength and colour), (4) the earliness or lateness, (5) the density of ear, (6) the susceptibility to rusts, and (7) the shape of the ear.

Percival (1921), in England, critically examined, for a period of over 20 years, living specimens in a worldwide collection and studied their morphological characters in the young and mature stages, especially their habit of growth, coleoptile nervation, ripening period, ear, grain characters, etc. He also suggested that greater emphasis should be placed on the characters of leaf and other vegetative organs as he felt that these characters were as stable and indicative of natural genetic relationships as the ear and grain characters. He suggested that within the botanical varieties recognized by Körnicke and Werner, 'types' or 'forms' needed to be recognized.

He further stated that the best way of dealing with such numerous and related forms was to make a separate classification of the forms cultivated in each country. For this purpose, he recommended that early growth habit, colour of leaves, and hairiness of leaf blades, in addition to the more commonly used morphological characters, as also resistance to pests, drought and fungal diseases, should be utilized.

Following on the line of thought enunciated by the Howards and Percival, a new concept of the classification of agricultural varieties was formulated by Pal *et al.* (1941). They pointed out that an idea of the range of variation present in the material concerned, from the genetical point of view, was more desirable than a formal botanical classification and description of the types themselves. Considering in detail each character for its usefulness from this point of view, they described the variation existing in the wheat types of India with regard to some agricultural, vegetative, spike and grain characters. They suggested, among other things, that the presence or absence of hairs on the leaf blade, sheath and auricles is likely to be of some value as taxonomic criteria. Harrington (1932) suggested that leaf pubescence could be used in differentiating two of the most common wheats of Canada in the seedling stage. Pal *et al.* (1952) suggested that while some aspects of leaf pubescence, such as arrangement, etc., are stable under different environmental conditions and as such reliable, caution was necessary in using the more variable quantitative aspects, such as density, length, etc.

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IV

CYTOGENETICS AND GENETICS

CYTOGENETICAL STUDIES

Genome analysis and origin. The discovery that species of *Triticum* form a polyploid series with n=7, 14 and 21 was made independently in the year 1918 by Sax in the United States and Sakamura in Japan. As Kihara (1958) pointed out, this finding has proved to be a very significant milestone in the history of wheat genetics. The search for the probable ancestors of bread wheat, which is a hexaploid, soon began and thanks to the detailed cytogenetical work carried out by Kihara and his co-workers in Japan, and McFadden and Sears in the United States, we now know the genome composition of *Triticum* species fairly definitely. Percival was the first to postulate that bread wheats arose from hybridization between a primitive emmer wheat (2n=28) and a diploid species of *Aegilops* (2n=14), followed by chromosome doubling. Thompson *et al.* (1943) were able to produce an allopolyploid from the hybrid *Triticum dicoccoides* and *Aegilops speltoides.* This artificial allopolyploid had mostly 21 bivalents at meiosis and was reasonably fertile. It could be crossed to *T. aestivum* and the hybrids were partly fertile and had rather irregular meiosis. Later, McFadden and Sears (1946) produced a somewhat similar allopolyploid, using as parents *T. dicoccoides* and *Ae. squarrosa.* This proved to be highly fertile and in external morphology it closely resembled the sub-species *spelta* of *T. aestivum.* F_1 hybrids between the synthetic allopolyploid and *T. spelta* had regular bivalent pairing at meiosis and were fully fertile, thus showing that the allopolyploid *T. dicoccoides* × *Ae. squarrosa* had essentially the chromosomal constitution of the bread wheats. Forms similar to *vulgare* type were obtained by Kihara by producing the allopolyploid of the hybrid *T. persicum* × *Ae. squarrosa.* There is little doubt, therefore, that the typical bread wheats originated from hybrids between the emmer wheats and the weedy grass, *Aegilops squarrosa.*

The origin of the tetraploid wheats is more obscure, because a much longer time has elapsed since these wheats arose. McFadden and Sears (1946) suggested that the Lake Dwellers' wheat may have been an amphidiploid of *T. monococcum* and *Agropyron triticeum.* They considered *T. persicum* to be a derivative of the Lake Dwellers' wheat. Camara (1936) proposed that the tetraploid wheats could have arisen from the diploids through autotetraploidy. Both these views have not found favour among subsequent workers since the subterminal chromosomes met with in *Agropyron triticeum* (Plate 16, *5*) do not occur in the emmer or bread wheats (Plate 16, *1-3*) and since both genetically and cytologically they behave as functional diploids. On the basis of the close morphological resemblance of the amphiploid of *T. monococcum* × *Aegilops bicornis* to *T. dicoccum,* Sears (1956) suggested that *Ae. bicornis* is the source of the B genome. Using

Anderson's method of extrapolation, Sarkar and Stebbins (1956) recently concluded that the species morphologically closest to the extrapolate is *Aegilops speltoides* and that this species might have been the donor of the B genome. Riley *et al.* (1958) supported the hypothesis of Sarkar and Stebbins on the basis of data from studies on chromosome morphology and pairing in hybrids involving members of the Sitopsis section of *Aegilops* and einkorn and emmer wheats. *Aegilops speltoides* is widely distributed in Asia Minor, Syria and Palestine. This, according to Vavilov (1949), is an area where wild forms of *T. monococcum*, *T. aegilopoides*, *T. thaoudar* and *T. dicoccoides* occur. The geographical distribution pattern would also, thus, support the view that *Ae. speltoides* contributed the B genome to emmer and bread wheats.

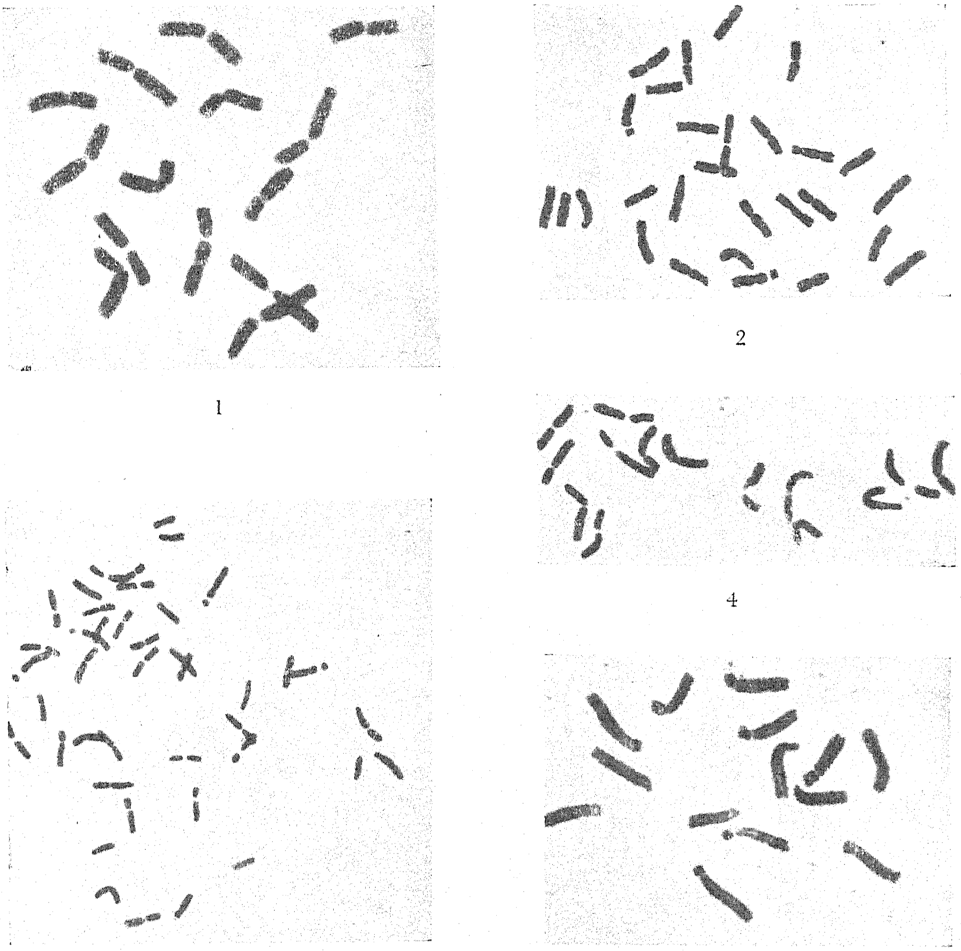
The genomic formulae given by Kihara for different *Triticum* species have been indicated in Table III (Chapter II). The correspondence of the genome A of the AB tetraploids with A of the diploids is by no means perfect but there seems little doubt that the former is derived from the latter. There is a general agreement concerning the close relationship of the two emmer genomes with the A and B of the hexaploids. G genome of *T. timopheevi* and *T. armeniacum* has been considered to have very little homology with the B of emmers. Love (1941) pointed out that the A of these two species is also probably differentiated from the A of the other tetraploid wheats. Recent evidence has, however, shown that the failure of pairing in F_1 hybrids between *T. timopheevi* and other tetraploid species is not due to lack of chromosome homology but is due to the presence in *T. timopheevi* of a gene which causes desynapsis in hybrid combinations. Hence, *T. timopheevi* should also be assigned the genome symbol AB. A new hexaploid species, *T. zhukovskyi*, described in 1958 by Menabde and Eritzan, has the genome constitution AAB having originated, in recent times, from a cross between *T. monococcum* and *T. timopheevi* (Upadhya and Swaminathan, 1963, 1965). The letter D was proposed by Kihara in 1924 to represent the third genome of the hexaploid wheats (Dinkel genome). American and British workers commonly use C instead of D, C being originally used by Gaines and Aase in 1926. Since much of the work on identifying and symbolizing the genomes of the relatives of wheat has been done by Kihara and his co-workers, who have based their designations on the use of D rather than C, and since D was proposed earlier than C, it would be proper if the use of D as a genome symbol is retained.

Chromosome morphology. Indian workers have contributed much information on the morphology of the chromosomes of *Triticum* species. Thus, on considerations of chromosome morphology, Pathak (1940) predicted that *Ae. squarrosa* may be the source of the D genome of hexaploid wheats, a prediction which has subsequently been verified. Bhaduri and Ghosh (1954a), and Bhaduri and Mazumdar (1955) described techniques for making squash preparations of chromosomes during mitosis in root tips and pollen grains respectively. Using these techniques, Bhaduri and Ghosh (1954b), and Bhaduri and Natarajan (1956a) found two chromosomal biotypes in *T. dicoccum* var. *Khapli*. Biotype I had two pairs of satellited chromosomes while Biotype II had only one such pair, thus suggesting the presence of intraspecific differences in chromosome morphology.

The karyotypes of some varieties of *T. aestivum* were studied by Bhaduri and Natarajan (1956b), who found a pair of satellited chromosomes with a double constricted region in the satellited portion in the Punjab wheat variety C. 591. Such a unique pair of satellited chromosomes was not observed in any other variety. In addition to this pair, C. 591 like all other bread wheat varieties had two pairs of satellited chromosomes, one of which had a relatively larger satellited portion in comparison with the other. A similar distinctive feature of satellited chromosomes was found in *T. macha* by Bhaduri and Ghosh (1955). In this hexaploid species, the two pairs of satellited chromosomes, one with median and another with sub-median primary constrictions, have in each another supernumerary constriction, thus rendering the karyotype of this species quite distinct from the other hexaploid species.

Chromosome pairing in polyhaploids. Meiosis in polyhaploid *T. aestivum* (2n=21) was described by Krishnaswamy (1939). Natarajan and Swaminathan (1958) found that treating plants with radioisotopes, like P^{32} and S^{35}, prior to anthesis is an effective means of obtaining polyhaploids in *T. aestivum*. Krishnaswamy (1939) found as many as nine bivalents in one cell of a polyhaploid, while Natarajan and Swaminathan observed a maximum frequency of five bivalents in haploids of bread wheat variety N.P. 809 (Plate 20). Pai and Swaminathan (1959) isolated a nulli-haploid (2n=20) in the variety N.P. 798. This nulli-haploid had several meiotic abnormalities, such as differential condensation, chromosome fragmentation and stickiness. Besides primary associations, secondary associations of the end-to-end (e-e), end-to-side (e-s) and side-to-side (s-s) types occur in the polyhaploids. The real significance of such associations has been a subject of controversy but recently Natarajan and Swaminathan (1958) have shown, with the help of chromosome markers, that secondary associations are restricted to specific regions within a chromosome. It is not yet known whether such regions are heterochromatic.

Genetic control of the cytologically diploid behaviour of hexaploid wheat. Though several bivalents are usually found in polyhaploids of *T. aestivum*, the hexaploid normally forms only 21 bivalents. This is surprising since there is considerable similarity between the chromosomes of *T. monococcum*, *Aegilops speltoides* and *Ae. squarrosa*, the three diploids from which the genomes of *T. aestivum* have been derived. Riley and Chapman (1958), and Sears and Okamoto (1958) recently showed that the diploid pairing of wheat is due to the presence of ' multivalent suppressor ' gene system in the long arm of chromosome V. Riley *et al.* (1959) further found that in the absence of the multivalent suppressor gene in chromosome V, pairing is permitted not only among the chromosomes belonging to the three genomes of bread wheat but also between the chromosomes of rye and wheat and of *Aegilops longissima* and wheat. Sears and Okamoto (1958) found that while in 27-chromosome plants from the cross mono V × einkorn, there were on an average ten bivalents per cell (range five to thirteen), the number of bivalents ranged only between two and seven in the 28-chromosome plants. In the 27-chromosome plants, there were some cells in which all the chromosomes were paired $(6_{IV}+1_{III})$ and trivalents and quadrivalents were common throughout. From these observations, they concluded that " the virtual failure of homoeologous chromosomes to pair appears to be due to suppression of pairing by chromosome V " and " it seems likely that the acquisition of a mutation on chromosome V which decreases pairing intensity is the means by which hexaploid wheat has achieved diploid pairing ". The existence of a gene system restricting pairing to completely homoeologous chromosomes provides an answer to the perplexing question as to why chromosomes so closely related genetically have so little tendency to pair. This finding also helps



1 2 3 4 5

PLATE 16. Somatic chromosomes in *Triticum* and allied genera (Magnification not the same)

1, *T. monococcum* (2n=14); 2, *T. durum* (2n=28); 3, *T. aestivum* (2n=42); 4, *Aegilops squarrosa* (2n=14); 5, *Agropyron triticeum* (2n=14). Note that in *A. triticeum* the chromosomes have all nearly subterminal constrictions.

(*Source:* Cytogenetics section, Division of Botany, I.A.R.I.)

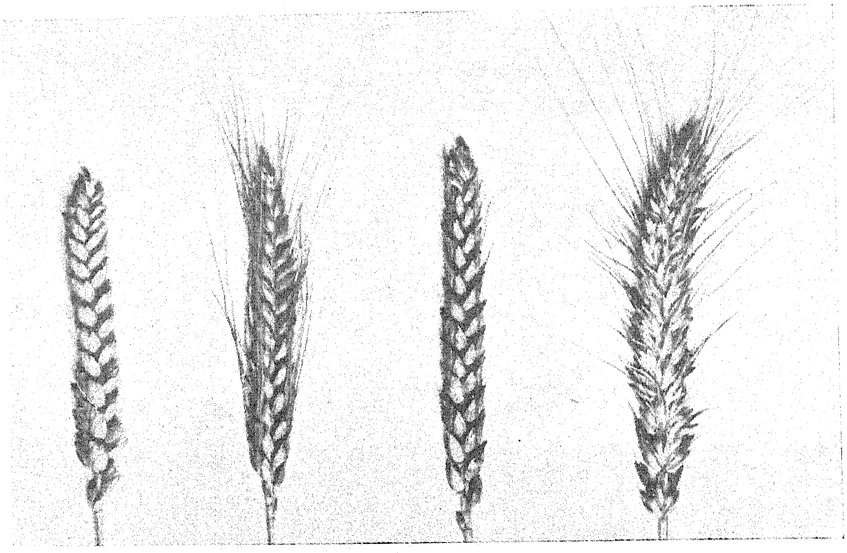


Plate 17. Monosomic analysis—B_2 in chromosome X (6B)

Left to Right : Chinese Spring monosome X; Cometa Klein; Chinese Spring X × Cometa Klein F_1 disome; Chinese Spring X × Cometa Klein F_1 monosome.

(*After* Sikka *et al.*, 1956; by courtesy of Editor, *Indian J. Genet.*)

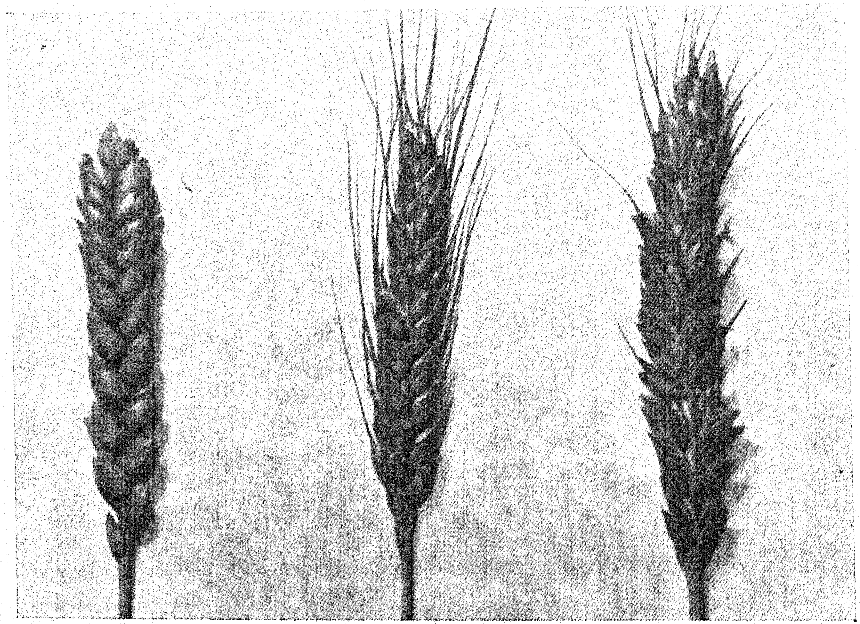


Plate 18. Monosomic analysis— *Hd* in chromosome VIII (4B)

Left to Right : Chinese Spring monosome VIII; Cometa Klein; Monosomic F_1 of Chinese Spring VIII × Cometa Klein.

(*After* Sikka *et al.*, 1956; by courtesy of Editor, *Indian J. Genet.*)

in understanding the question of the ancestry of tetraploid wheat. As pointed out earlier, recent morphological and cytological studies indicate that *Aegilops speltoides* is the source of the B genome. But einkorn-speltoides amphidiploids have many multivalents and are highly infertile. If the chromosome V effect is real, then it is possible that this amphidiploid became fertile and stable through the acquisition of such a genetic mechanism and thereby became the progenitor of tetraploid wheat. The findings of Riley and Chapman (1958), and Sears and Okamoto (1958) are, thus, of great significance to workers in both wheat breeding and polyploid plant evolution.

Aneuploid analysis. The progress in wheat genetics owes much to the establishment of a complete series of monosomics ($2n=41$) in the variety Chinese Spring by Sears (1939, 1944). A recent list of the genes located on specific chromosomes of bread wheat through aneuploid analysis, compiled by Dr. Rosalind Morris of the University of Nebraska, reveals how great an impact this elegant tool has made on the study of linkage groups in this hexaploid plant. In general, genetic analysis is carried out by studying: (a) the differences in morphological characters between F_1 plants with $2n=41$ and $2n=42$; (b) the F_2 segregations in order to identify the chromosome lines which give rise to skewed ratios; and (c) the characteristics of nullisomics. Already, these methods have been used by several wheat cytogeneticists and a good start has been made towards mapping the chromosomes. Several genes for disease resistance as well as some for morphological characters have been identified. Another important use of the aneuploids is that they can be used for substituting a pair of chromosomes of one variety into another. Such substitution lines have been useful not only in identifying the genes controlling qualitative characters but also in studying the location, possible number and interaction of genes governing quantitative expression. Thus, Kuspira and Unrau (1957) found statistically highly significant modifications of yield, earliness, lodging resistance and height associated with specific chromosomes of Thatcher, Hope and Timstein substituted for their respective homologues in lines of Chinese Spring. O'Mara (1947) found that when a pair of hairy-neck chromosomes from rye was substituted for the chromosome pair IX of wheat, a more nearly normal plant was obtained than when the rye pair was simply added to the entire wheat complement. It is possible that certain other chromosomes from rye or from other genera related to wheat might advantageously be substituted for specific wheat chromosomes.

The chromosomes of Chinese Spring have been numbered by Sears from I to XXI. Of these, chromosomes XV to XXI represent the D genome chromosomes. Those belonging to the A and B genomes have been lumped together as numbers I to XIV. Larson (1952) suggested that chromosomes II, III, IV, V, VI, VII and XIV may constitute the A genome. But this does not seem to be correct since from the observations of Pathak (1940) it is clear that one of the two nucleolar chromosomes of tetraploid wheat is in the A genome and since Morrison (1953) has shown that chromosomes I and X are the satellited chromosomes. Pathak (1940) pointed out that it is presumably the shorter, satellited nucleolar chromosome which was derived from diploid wheat. This would be chromosome X and the long, secondarily constricted chromosome (chromosome I) would then belong to genome B.

Largely through tests of the ability of particular tetrasomes to compensate for particular nullisomes, Sears (1954) placed the 21 chromosomes of wheat into seven homoeologous groups of three. Within each group, the tetrasome of each chromosome compensates, at least in part, for the nullisome of each of the other two chromosomes. The seven groups are:

1. I, XIV, XVII
2. II, XIII, XX
3. III, XII, XVI
4. IV, VIII, XV
5. V, IX, XVIII
6. VI, X, XIX
7. VII, XI, XXI

The identification of the chromosomes belonging to the different genomes is now practically complete and it is possible to assign each chromosome, except possibly II and XIII, to its respective genome. Sears (1959) further proposed the following revised nomenclature for the chromosomes of *T. aestivum.*

Homoeologous group	Genome A		Genome B		Genome D	
	New	Old	New	Old	New	Old
1	1A	XIV	1B	I	1D	XVII
2	2A	II	2B	XIII	2D	XX
3	3A	XII	3B	III	3D	XVI
4	4A	IV	4B	VIII	4D	XV
5	5A	IX	5B	V	5D	XVIII
6	6A	VI	6B	X	6D	XIX
7	7A	XI	7B	VII	7D	XXI

The new system has the great merit in that from the number of the chromosome both the genome and the homoeologous group to which it belongs can be recognized at once.

In India, monosomic analysis in varieties of bread wheat has been in progress at the Indian Agricultural Research Institute since 1954. The chromosomes carrying genes conferring resistance to black, brown and yellow rusts have been identified in several varieties. The genes governing awn development and glume-beak shape were located on specific chormosomes in the varieties Cometa Klein and N.P. 790 (Sikka *et al.*, 1956, 1959; Singh and Swaminathan, 1959; *see also* Plates 17–19). An interesting finding is the identification of an allele of the epistatic gene **B**$_2$ on chromosome X(6B); this reduces the fully awned condition into a half bearded one. The presence of this gene, designated **B**$_2$, was first postulated by Watkins and Ellerton (1940) but has never been confirmed.

A comprehensive list of genes identified in different chromosomes by aneuploid analysis as well as the morphology of the individual chromosomes as described by Morrison (1953) is given in Plate 21. The three homoeologous chromosomes have been put together in one column and, thus, there are seven groups. This list will serve as an adequate testimony to the great contribution made by the technique of monosomic analysis in the understanding of the genetic make-up of wheat. The value of such knowledge for wheat improvement is obvious.

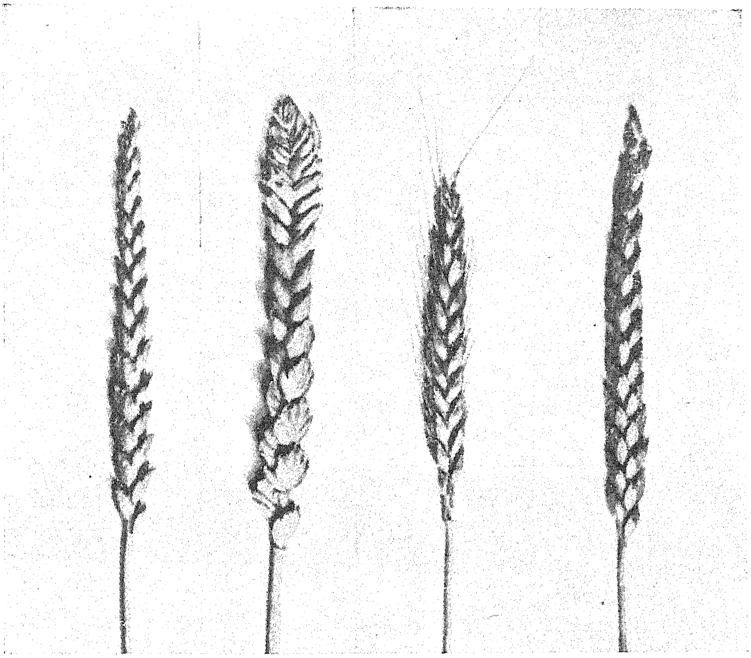


PLATE 19. Monosomic analysis—*Q* in chromosome IX(5A)

Left to Right : Chinese Spring monosome ~~XI~~ IX; Chinese Spring disome ~~XI~~; Cometa Klein; Monosomic F_1-Chinese Spring ~~XI~~ IX × Cometa Klein.

(*After* Sikka *et al.*, 1956; by courtesy of Editor, *Indian J. Genet.*).

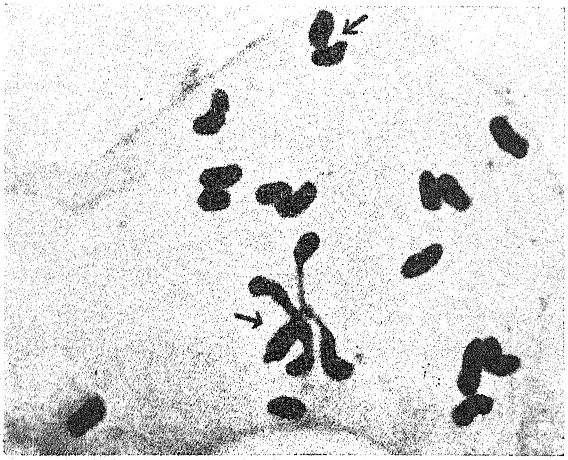


PLATE 20. PMC of a haploid N.P. 809 plant, showing 17 univalents and two bivalents. Several univalents show s-s associations. Sat. I univalent is attached at the distal end to a bivalent. Sat. II chromosome is also marked by an arrow. (× 1,400).

(*Source:* Cytogenetics Section, Division of Botany, I.A.R.I.).

HOMOEOLOGOUS GROUP I

CHROMOSOME I

- PLANT HEIGHT
- TILLERING
- LODGING RESISTANCE
- EARLINESS
- YIELD
- SPIKE DENSITY
- STIFF GLUME INHIBITION
- RED OR BROWN GLUMES
- FERTILITY
- KERNEL WEIGHT

CHROMOSOME XIV

- PLANT HEIGHT
- LEAF WIDTH
- CULM THICKNESS
- SPIKE LENGTH
- PUBESCENT GLUMES
- FERTILITY
- LEAF RUST RESISTANCE

CHROMOSOME XVII

- PLANT HEIGHT
- TILLERING
- PROCUMBENT TILLERING
- LEAF WIDTH
- CULM THICKNESS
- AWN SUPPRESSION
- EARLINESS
- SPIKE LENGTH
- FERTILITY
- YIELD
- SEEDLING STEM RUST RESISTANCE

HOMOEOLOGOUS GROUP II

CHROMOSOME II

- PLANT HEIGHT
- TILLERING
- LEAF SIZE
- CULM DIAMETER
- SOLID CULM INHIBITION
- LODGING RESISTANCE
- EARLINESS
- SPIKE DENSITY
- ANTHER SIZE
- YIELD

RIGHT ARM

- GLUME TOUGHNESS
- AWN PROMOTION
- NORMAL SYNAPSIS
- FEMALE FERTILITY

LEFT ARM

- INTERNODE LENGTH
- NON-REDUPLICATION OF SPIKELETS

CHROMOSOME XIII

- PLANT HEIGHT
- DWARF PLANTS
- TILLERING
- LEAF DEVELOPMENT
- SOLID CULM INHIBITION
- SPRING GROWTH HABIT
- LODGING RESISTANCE
- EARLINESS
- BASAL SPIKELET DEVELOPMENT
- GLUME DEVELOPMENT
- SEEDLING STEM RUST RESISTANCE
- ADULT STEM RUST RESISTANCE
- POWDERY MILDEW RESISTANCE

RIGHT ARM

- SPIKE INTERNODE LENGTH
- AWN PROMOTION
- FEMALE FERTILITY

CHROMOSOME XX

- PLANT HEIGHT
- TILLERING
- SOLID CULM INHIBITION
- EARLINESS
- LODGING RESISTANCE
- COMPACTUM OR CLUB SPIKE
- SPIKE DENSITY
- STEM RUST RESISTANCE

RIGHT ARM

- AWN DEVELOPMENT
- FEMALE FERTILITY

HOMOEOLOGOUS GROUP III

CHROMOSOME III

- PLANT HEIGHT
- LODGING RESISTANCE
- SOLID TOP INTERNODE OF CULM
- EARLINESS
- YIELD
- NEATBY'S VIRESCENT
- NECROTIC LEAVES
- LEAF DEVELOPMENT
- SPIKE DENSITY
- SPIKE LENGTH
- AWN EXPRESSION
- NORMAL SYNAPSIS
- SEEDLING RESISTANCE TO STEM RUST (COMPLEMENTARY GENE ON XIII)
- ADULT STEM RUST RESISTANCE
- PSEUDO-BLACK CHAFF SUSCEPTIBILITY
- STRIPE RUST RESISTANCE
- BROWN NECROSIS SUSCEPTIBILITY
- LEAF RUST RESISTANCE

CHROMOSOME XII

- PLANT HEIGHT
- LEAF DEVELOPMENT
- EARLINESS
- LODGING RESISTANCE
- SPIKE DENSITY
- SPIKE LENGTH
- AWN EXPRESSION
- FERTILITY
- YIELD
- SEED LETHALITY

CHROMOSOME XVI

- LEAF DEVELOPMENT
- TILLERING
- ROOT DEVELOPMENT
- EARLINESS
- LODGING RESISTANCE
- SPIKE DENSITY & LENGTH
- SPHAEROCOCCUM CHARACTERS
- FERTILITY
- KERNEL WEIGHT
- YIELD
- PROTEIN CONTENT
- SEED LETHALITY

RIGHT ARM

- PLANT HEIGHT
- AWN INHIBITION
- RED SEEDS

HOMOEOLOGOUS GROUP IV

CHROMOSOME IV

- PLANT HEIGHT
- EARLINESS
- LEAF WIDTH
- CULM THICKNESS
- LODGING RESISTANCE
- SPIKE DENSITY
- AWN EXPRESSION (INTER ACTION WITH GENES ON VIII AND X)
- MALE FERTILITY
- KERNEL WEIGHT
- YIELD
- SEED SHAPE
- YELLOW RUST RESISTANCE

CHROMOSOME VIII

- PLANT HEIGHT
- DWARF PLANTS (COMPLEMENTARY GENE ON XIII)
- LEAF WIDTH
- CULM THICKNESS
- SOLID CULM
- TILLERING
- EARLINESS
- LODGING RESISTANCE
- SPIKE LENGTH
- SPIKE DENSITY
- AWN INHIBITION
- HOODED AWN (Hd)
- MALE FERTILITY
- YIELD
- SEEDLING STEM RUST RESISTANCE
- ADULT STEM RUST RESISTANCE (COMPLEMENTARY GENES ON III AND XIII)
- STRIPE RUST RESISTANCE

CHROMOSOME XV

- PLANT HEIGHT
- LEAF WIDTH
- CULM THICKNESS
- EARLINESS
- SPIKE LENGTH
- MALE FERTILITY
- PROTEIN CONTENT
- STEM RUST RESISTANCE (ONE OF 2 GENES)

HOMOEOLOGOUS GROUP V

CHROMOSOME V.

- PLANT HEIGHT
- LEAF WIDTH
- CULM THICKNESS
- SOLID LOWER INTERNODE OF CULM
- EARLINESS
- LODGING RESISTANCE
- SPIKE DENSITY
- SPIKE SIZE
- GLUME SIZE
- MALE FERTILITY
- KERNEL WEIGHT
- YIELD
- PROTEIN CONTENT
- ASYNAPSIS
- MULTIVALENT SUPPRESSOR

CHROMOSOME IX

- PLANT HEIGHT
- SOLID LOWER INTERNODES OF CULM
- LODGING RESISTANCE
- EARLINESS
- MALE FERTILITY
- YIELD
- PROTEIN CONTENT
- HAIRY NODE
- HAIRY LEAF
- AWN SUPPRESSION

LONG ARM

- LEAF WIDTH
- CULM THICKNESS
- PUBESCENT NODES
- SPELTOID SUPPRESSION & SQUARE HEADEDNESS
- AWN INHIBITION (B_1 B_{1a})
- SPRING GROWTH HABIT
- RESISTANCE TO YELLOW RUST

CHROMOSOME XVIII

- LEAF WIDTH
- CULM THICKNESS
- SOLID LOWER INTERNODES OF CULM
- TILLERING
- SPRING GROWTH HABIT
- EARLINESS
- SPIKE SIZE
- GLUME SIZE
- MALE FERTILITY
- SEED SIZE
- YIELD

HOMOEOLOGOUS GROUP VI

CHROMOSOME VI

- PLANT HEIGHT
- TILLERING
- LEAF WIDTH
- CULM THICKNESS
- EARLINESS
- LODGING RESISTANCE
- SPIKE DENSITY
- SPIKE LENGTH
- OUTER GLUME DEVELOPMENT
- KERNEL WEIGHT
- YIELD
- MALE FERTILITY
- SEEDLING STEM RUST RESISTANCE
- YELLOW RUST RESISTANCE

CHROMOSOME X

- SUPPRESSION OF LEAF NECROSIS
- LEAF WIDTH
- CULM THICKNESS
- EARLINESS
- NORMAL OUTER GLUMES
- AWN INHIBITION
- SPIKE DENSITY
- SUPPRESSION OF PISTILLODY
- KERNEL WEIGHT
- YIELD
- SEEDLING LEAF RUST RESISTANCE (COMPLEMENTARY GENES)
- MATURE LEAF RUST RESISTANCE (COMPLEMENTARY GENES)
- STEM RUST RESISTANCE (2 LINKED COMPLEMENTARY GENES)

CHROMOSOME XIX

- PLANT HEIGHT
- LEAF WIDTH
- CULM THICKNESS
- SOLID CULM INHIBITION
- EARLINESS
- LODGING RESISTANCE
- OUTER GLUME DEVELOPMENT
- SPIKE DENSITY
- KERNEL WEIGHT
- YIELD
- SEEDLING STEM RUST IMMUNITY

HOMOEOLOGOUS GROUP VII

CHROMOSOME VII

- PLANT HEIGHT
- LEAF WIDTH
- EARLINESS
- LODGING RESISTANCE
- CULM COLOUR
- SPIKE DENSITY
- SPIKE LENGTH
- YIELD
- LEAF RUST RESISTANCE
- PROTEIN CONTENT

CHROMOSOME XI

- PLANT HEIGHT
- SPIKE DENSITY
- SUPPRESSION OF PISTILLODY
- RED COLEOPTILE
- MILDEW RESISTANCE
- SEEDLING STEM RUST RESISTANCE

CHROMOSOME XXI

- PLANT HEIGHT
- LEAF WIDTH
- SOLID CULM INHIBITION
- EARLINESS
- LODGING RESISTANCE
- SPIKE DENSITY
- SPIKE LENGTH
- AWN EXPRESSION
- YIELD

PLATE 21. Homoeologous groups in wheat and the characters located on each chromosome through monosomic analysis

GENETICAL STUDIES

In view of its polyploid nature, bread wheat offers limited scope for formulating a precise picture of different genotypes through the application of normal genetical methods of analysis. It is for this reason that aneuploid analysis has played such an important role in wheat genetics. However, information on the number of loci for which a given pair of varieties are unlike can be readily obtained by analysing the F_2 and backcross populations. Much work has been done in India in this field; a summary of the same is given below.

(a) **Awn development.** The early work of Howard and Howard (1912, 1915) indicated that awning is controlled by two pairs of factors in the intervarietal crosses of *T. aestivum* studied by them. In the F_2 generation they found a 15 awned (various grades): 1 awnless segregation. Abbasi (1949), in the cross Premier × Kenya R.L. 1373, observed that the inheritance of awnedness was dependent on a single-factor pair. Sen and Joshi (1955) found that awning was controlled by a single-gene pair in crosses of the fully awned N.P. 761, Niphad-4 and Pb.C. 591 with the long-tipped Gabo. Pal *et al.* (1956) studied the mode of inheritance of the awn character in two crosses—N.P. 789 (awnless) × Frondoso (fully awned) and Ridley (tipped) × Pb.C. 518 (fully awned). They found that awning was controlled in the first cross by duplicate factors and in the second cross by a single-factor pair (Plate 22). Sikka and Rao (1957) studied five crosses of the variety N.P. 790 (awnless) with fully awned varieties such as N.P. 710, N.P. 718, N.P. 781, Pb.C. 281 and Pb.C. 591 and found that awning in each of these crosses was conditioned by duplicate factors. In the F_2 they obtained a ratio of 15 tipped: 1 fully awned. Similar results were reported by Ghosh *et al.* (1958) in the cross N.P. 790 × N.P. 775 (fully awned), and by Prasad and Rao (1961) in the crosses Pb.C. 518 × N.P. 790 and E. 871 (fully awned) × N.P. 165 (awnless).

Monosomic analysis has revealed that awning in bread wheat is controlled by a series of awn promotor genes and three major epistatic genes—**Hd** on chromosome VIII (4D), $\mathbf{B_1}$ on IX(5A) and $\mathbf{B_2}$ on X(6B). Sikka *et al.* (1956) observed awns in nullisomes of Chinese Spring wheat for chromosomes VIII and X. This would seem to suggest that in the absence of **Hd** and $\mathbf{B_2}$ awn development is permitted. A series of **A** genes have been proposed by Heyne and Livers (1953) to explain awn development in different varieties. An **A** gene is hypothetically non-epistatic but incompletely dominant over an awn producing **a** allele. A single locus in the homozygous recessive condition **aa** theoretically could produce full awns, if not inhibited by partially epistatic **Hd** or $\mathbf{B_1}$ or $\mathbf{B_2}$.

Singh *et al.* (1957) studied the inheritance of awning in the following interspecific crosses: *T. aestivum* (N.P. 165 awnless) × *T. vavilovi* (long-tipped); *T. aestivum* (N.P. 114, fully awned) × *T. vavilovi; T. sphaerococcum* (long-tipped to half-awned) × *T. vavilovi.* The F_1 was short-tipped in the first cross and half-awned in the others. On the basis of segregations in F_2 and F_3 they came to the conclusion that N.P. 165 showed a two-factor difference and the other two, viz., N.P. 114 and *T. sphaerococcum,* a one-factor difference from *T. vavilovi.* The segregation data obtained from the cross involving N.P. 165 as one of the parents confirmed the earlier findings of Howard and Howard (1912, 1915) that N.P. 4 and Federation, both awnless, differed from the fully awned condition by two genes which individually determine the half-awned and long-tipped conditions.

(b) **Awn colour.** Howard and Howard (1912, 1915) observed in a cross between black-awned and white-awned varieties a simple monogenic segregation for awn colour in the F_2 generation. Later studies by Kadam and Nazareth (1931) showed that black and red awn colours are determined by two separate factors **B** (producing black colour and epistatic to **R**) and **R** (producing red awn colour). In a cross between the black-awned variety *Kala Khapli* 568 (*T. dicoccum*) and the red-awned variety *Bansi* 103 (*T. durum*), the black awn colour was dominant in F_1 and in F_2; they obtained a ratio of 12 black: 3 red: 1 white. The studies of Ghosh *et al.* (1958) showed similar results in the crosses, Pb.C. 281 (black) × Cometa Klein (brown) and N.P. 718 (white) × Cometa Klein.

(c) **Glume colour.** Red glume colour is due to a single factor according to Howard and Howard (1912, 1915), and Kadam (1936). This gene **Rg-a** also produces red awn colour but is hypostatic to the black awn colour gene **B** in the awn region. Pal *et al.* (1956), Sikka and Rao (1957), Ghosh *et al.* (1958), and Prasad and Rao (1961) observed in crosses between varieties with white and brown glumes that the F_1 had brown glumes. They found from the mode of inheritance that brown glume colour is controlled by a single-factor pair. Ayad (1952), Sen and Joshi (1955), and Sears (1948) obtained data on the inheritance of glume colour which were explainable on two pairs of factors in the former two cases and three major factors in the last case.

(d) **Glume hairiness.** The hairs on the chaff of felted wheats vary considerably in length and density. Each kind of hair is due to a single factor and these factors are inherited independently of each other (Howard and Howard, 1912, 1915). Kadam (1936) found that hairiness of glumes in *Kala Khapli* 568 is determined by a single gene and is dominant to the glabrous condition in *Bansi* 103. Sikka and Rao (1957) studied the mode of inheritance of glume hairiness in five crosses. In all the crosses, in the F_1 hairiness of the glumes was found to be dominant over the glabrous character. From the F_2 and F_3 data they concluded that the character glume hairiness is monogenic and is simply inherited. In F_3 generation, however, certain families were obtained which were less pubescent than the pubescent parents which entered the crosses. Apparently, in addition to the one major factor, there may be some minor or modifying genes influencing the pubescent character. Pal *et al.* (1956), Ghosh *et al.* (1958), Sikka *et al.* (1960 a,b), and Prasad and Rao (1961) also reported glume pubescence to be monogenically controlled. *T. vavilovi* and variety N.P. 114 of *T. aestivum* have pubescent glumes while *T. sphaerococcum* and the variety N.P. 165 of *T. aestivum* are glabrous. Crosses involving these showed a monogenic difference in respect of this character (Singh *et al.*, 1957).

(e) **Grain colour.** Howard and Howard (1912) found that the red colour of the grain may be due to the presence of one, two or three factors which are inherited independently and which are individually capable of producing red colouration of variable grades. According to Kadam (1936), red grain colour of the *dicoccum* variety *Khapli* 568 is dominant to the yellow grain colour of *Bansi* 103 (*T. durum*). Sikka and Rao (1957) studied the inheritance of grain colour in 11 crosses involving red-grained and amber-grained varieties. They found that in all crosses the red-grained character was dominant over the amber-grained condition; and further that N.P. 790 carried one pair of dominant factors for red grain colour while Kenya

184-P.2-A.I.F. and Frontiera carried two and three pairs respectively. Amber colour was found to be the bottom recessive. Ghosh *et al.* (1958) reported that the red grain colour of Cometa Klein in crosses with N.P. 718 and C. 281 was governed by two-factor pairs.

(f) **Waxy bloom.** Several varieties of common wheat (*T. aestivum*) and of other species are glaucous on various parts of the plant, e.g., leaves, leaf sheaths, glume surface, etc. In a cross involving the *aestivum* type W.R. 113 (non-glaucous) and the glaucous species *T. vavilovi*, Singh *et al.* (1957) observed that glaucousness was dominant in the F_1. From the F_2 and F_3 data they concluded that glaucousness of *T. vavilovi* was conditioned by two duplicate factors. Prasad and Rao (1961) found that the glaucousness of E. 871 (Timstein derivative) is governed by a single dominant factor in crosses with N.P. 718 and N.P. 165 (non-glaucous).

(g) **Spring vs. winter habit and spike density.** In interspecific crosses involving *T. aestivum*, *T. vavilovi* and *T. sphaerococcum*, Singh *et al.* (1957) found that the inheritance of these characters was apparently multigenic. Again, no segregates with *vavilovi* type spikelets (i.e., with elongate rachillae) occurred which were also not speltoid. No fully awned segregates were found which had elongate rachillae.

The inheritance of early growth habit was studied by Ghosh *et al.* (1958) and Lakhani (1956) in certain crosses of common bread wheat. It was observed that spreading habit differed from the erect habit by two-factor pairs while erect and semi-spreading habits differed by a single-factor pair.

(h) **Dwarfism.** Inheritance of dwarfism or grass clump habit was studied by Prasad and Rao (1961) in a number of crosses, involving the parents Pb.C. 281, Pb.C. 518, Frontiera, E. 871 (Timstein derivative), Pb.C. 273 and N.P. 790. It was found that this character is governed by three recessive duplicate factors. In certain other crosses this character was found to be controlled by one or two inhibitory factors. In still others complementary factors appeared to control this character. Thus, in crosses Gabo × E. 871, La Prevision × Gabo, Pb.C. 591 × Kenya 338.AC.2.E.2,1-49-89, La Prevision × Kenya 338.AC.2.E.2,1-49-89, Pb.C. 591 × (Kenya-Gular-Pilot) K 58—New Thatch, all the F_1 plants were grass clumps (Unpub. work, Bot. Div., I.A.R.I.).

(i) **Leaf blotching.** Sikka and Jain (1959) studied the inheritance of leaf blotching in the cross N.P. 718 × (Supremo × Mentana) and found it to be governed by a single recessive gene. Prasad and Rao (1961) noted similar mode of segregation for this character in the cross Pb.C. 273 × N.P. 790.

(j) **Anthocyanin pigmentation of the rachis.** This character, studied by Prasad and Rao (1961) in the crosses Pb.C. 273 (normal) × N.P. 790 (pigmented) and Pb.C. 518 (normal) × N.P. 790, was found to be governed by a single dominant gene. But its expression was inhibited by another factor which produced normal colour of the rachis.

(k) **Glume beak.** Obtuse beak was dominant over acuminate beak. Two factors were involved in controlling this character (Prasad and Rao, 1961) in the crosses Pb. C. 518 (acuminate) × N.P. 790 (obtuse) and E. 871 (acuminate) × N.P. 165 (obtuse).

(l) **Glume shoulder.** The character square glume shoulder was dominant over 'wanting' shoulder and governed by a single factor in the crosses Pb.C. 518

(wanting) ×N.P. 790 (square) and Pb.C. 273 (wanting) ×N.P. 790 (Prasad and Rao, 1961).

(m) **Other characters.** A number of other characters, such as shedding of the awns, awn arrangement (adpressed vs. spreading), ear alignment (erect vs. drooping), grain texture (hard vs. soft) and grain lustre (dull vs. lustrous), were studied by Prasad (1959) in crosses involving E. 871, Frontiera, N.P. 165, Pb.C. 281, N.P. 718 and Pb.C. 518. All these characters were found to be single-gene controlled.

(n) **Inheritance of field resistance to rust.** When crosses are made between rust-resistant and susceptible parents, the resulting offspring may exhibit resistance in some cases, susceptibility in others while in still other cases the reaction of the F_1 generation may be intermediate between the two parents. In India, field resistance to black rust was observed to be dominant in some crosses and recessive in certain others (Pal, 1951). Kulkarni (1934) showed that the Hope type of resistance was due to a single factor; rust reaction was not correlated with the presence of ligule (which was determined by two dominant factors) or with yield. Abbasi (1949) reported the inheritance of mature plant and physiological resistance to stem rust and leaf rust in crosses between Premier and Kenya wheats. He found that the mature plant resistance to stem rust was dependent upon two-factor pairs; a dominant gene **H** is carried by Premier while Kenya R.L. 1373 carried another dominant gene **K**. The type of resistance due to **H** was found to be epistatic to that due to **K**. Inheritance of leaf-rust resistance was observed to be governed by a single dominant gene.

Sen and Joshi (1955) reported that in the crosses Kenya E. 220 (resistant) × Pb.C. 591 (susceptible), Gabo (resistant) × N.P. 761 (susceptible) and Gabo × N.P. 52 (susceptible), resistance was controlled by a single gene. In the crosses, Gabo (resistant) ×N.P. 165 (susceptible) and Gabo ×N.P. 52 (susceptible), resistance was found to be controlled by duplicate factors (*Ann. Rep. C.W.R.C.*, 1953). When Egypt N.A. 95 (resistant) was crossed with N.P. 52 and N.P. 165, digenic segregations of 9 susceptible: 7 resistant and 15 susceptible: 1 resistant plants were observed. Das (1954) in a cross of Ridley (susceptible) with the resistant N.P. 789 noted field resistance to stem rust to be controlled by three complementary factors (27 resistant: 37 susceptible). Pal *et al.* (1956) also observed in the cross N.P. 789 (resistant) ×Frondoso (susceptible) that the F_1 was resistant to a mixture of races of black rust (excluding race 122) in the adult stage. They explained the data obtained in F_2 and F_3 on the basis of three complementary genes. Field reaction to brown rust and yellow rust in this cross was also studied by the same authors. They found that field reaction to brown rust was controlled by two complementary factors; field resistance to yellow rust was found to be conditioned by three factors—one independent factor in addition to two complementary factors. Sikka and Rao (1958) investigated the breeding behaviour of the variety N.P. 790 with regard to field resistance to black rust in crosses with three susceptible varieties, viz., N.P. 718, Pb.C. 281 and Pb.C. 591. In the cross N.P. 718 × N.P. 790 resistance was dominant in F_1 and the F_2 and F_3 data showed that a single-factor pair conditioned the resistance. In the other two crosses, Pb.C. 591 × N.P. 790 and Pb.C. 281 ×N.P. 790, susceptibility was dominant in F_1, and the F_2 and F_3 data showed that three factors were operative. They explained the data assuming

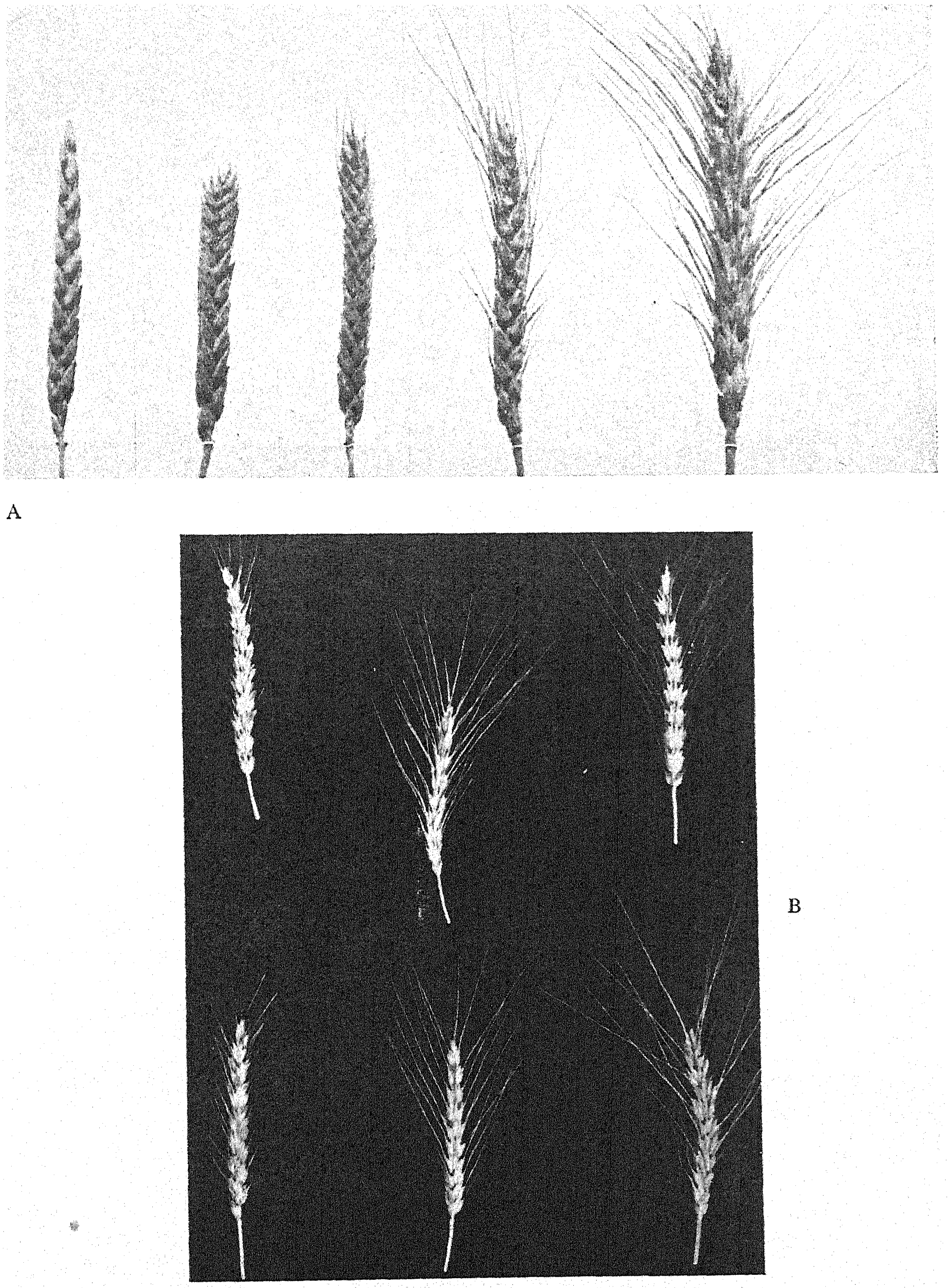


Plate 22 A. Segregation for awning in F_2 of cross of Beardless × Fully bearded

Left to Right: Beardless short tipped, long tipped, half bearded, fully bearded

B. One-factor segregation for awning in a cross between a reduced awn and fully awned varieties

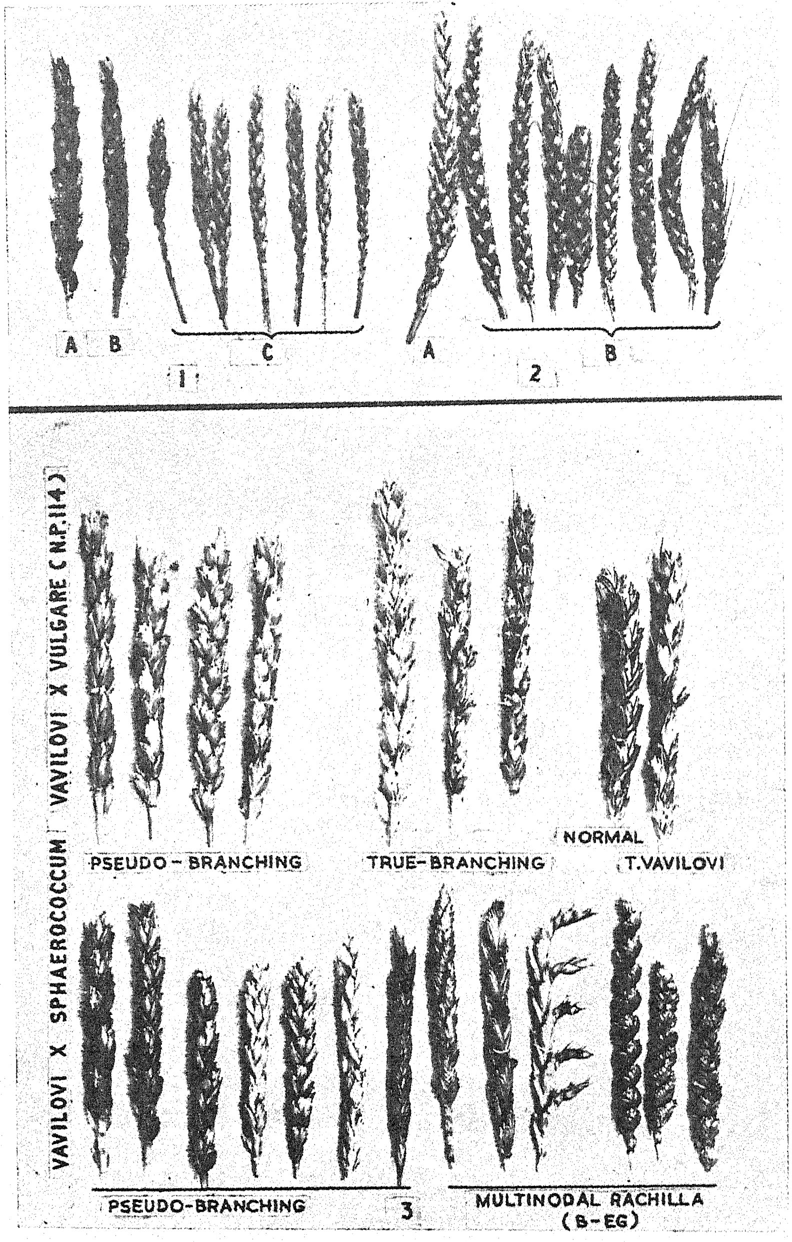


PLATE 23.
1. A, ear of *Triticum vavilovi* (Simla grown); B, ear of *T. vavilovi* (Delhi grown); C, variation in extent of branching in the ears of the same plant of *T. vavilovi.*
2. Ears of the F_3 progeny of a true branching F_2 plant. A, branched ear; B, non-branched ear.
3. Various types of branching and extra glume derivatives.

(*After* Singh *et al.*, 1957; by courtesy of Editor, *Agronomy Journal*) that the two Punjab wheats carry either two inhibitory genes or two dominant genes for susceptibility which suppressed the expression of the resistance of N.P. 790. These findings were further confirmed by Prasad and Rao (1961) in cross of N.P. 790 with two more Punjab wheats, viz., Pb.C. 518 and Pb.C. 273. The mode of inheritance of field resistance of Kenya 184.P.2.A.I.F. to black rust was studied by Sikka *et al.* (1961 b) in crosses with two susceptible wheats, N.P. 710 and Pb.C. 281; susceptibility was dominant in the F_1 generation. F_2 and F_3 data indicated that the resistance of Kenya 184. P.2.A.I.F. is governed by two recessive duplicate genes.

Field resistance of N.P. 785 and La Prevision to yellow rust in the crosses, N.P. 785 × N.P. 710, N.P. 785 × N.P. 718 and La Prevision × N.P. 710, was found to be governed by two factors by Sikka *et al.* (1961 a, b). They also reported that a single recessive factor in Frontiera and two recessive factors in La Prevision govern field resistance to brown rust.

Murty and Lakhani (1958) studied the mode of inheritance of field resistance of Gaza (*Triticum durum*) to black and brown rusts in crosses with *aestivum* wheats, N.P. 710, N.P. 718, Pb.C. 281 and Pb.C. 591. Resistance to black rust was governed by two factors in some and three in others. Similarly, resistance to brown rust was controlled by two factors in some and by one in others.

Inheritance of field resistance of E. 871 (Timstein derivative) was studied by Rao and Prasad (Unpub.) in crosses with susceptible N.P. 718, N.P. 165 and Pb.C. 281 and found to be governed by two recessive duplicate factors.

A summary of the field studies carried out with the three rusts in India is given in Table IV.

(o) **Inheritance of seedling resistance to individual races.** Studies on the inheritance of seedling or physiologic resistance to different races of the rusts found in India were taken up only recently. Abbasi (1949) reported that reaction to race 34 of stem rust is governed by a single gene in the crosses of Premier and certain Kenya wheats. Athwal (1953), working with race 42, observed that the resistance of the varieties Eureka, Ben Cubbin, Mentana, Dundee and Uruguay was simply inherited. A study of crosses among various resistant varieties showed that the single gene in Eureka and Ben Cubbin were allelomorphic and that the factor in Eureka was either allelic or linked with one of the two factors in Kenya 117A and the single factor in Uruguay. The single factor in Mentana was found to be inherited independently of the resistance factors present in certain other varieties. He also found that in Eureka, factors conditioning resistance to race 42 and race 21 were independent.

Sen and Joshi (1955) reported that in the cross, Kenya E. 220 (resistant) × Pb.C. 591 (susceptible), reaction to race 42 is governed by a single gene. Rao and Agrawal (1960 a, b, c) studied the inheritance of seedling resistance to races 42, 40, 75, 24, 117, 34 and biotypes 42B and 21A of black rust in a number of intervarietal crosses of *Triticum aestivum*. Sikka *et al.* (1961 b) reported similar results with races 15 and 21, and Rao *et al.* (1962) for the biotype 15C and its colour mutant. The results are summarized in Table V. The results so far obtained indicate that seedling resistance to most of the black rust races met with in India is governed by one or two genes, except in the case of E.1913, where three factors were found to operate against races 24 and 117. Attempts so far

TABLE IV. MODE OF INHERITANCE OF FIELD RESISTANCE TO RUST IN WHEAT

Sl. No.	Cross	Resistant parent	Mode of segregation
	A. Black rust		
1.	Kenya E. 220 × Pb. C. 591	Kenya E. 220	3R : 1S
2.	Gabo × N.P. 761	Gabo	3R : 1S
3.	Gabo × N.P. 52	Gabo	3R : 1S
4.	Ridley × N.P. 789	N.P. 789	27R : 37S
5.	N.P. 789 × Frondoso	N.P. 789	27R : 37S
6.	N.P. 718 × N.P. 790	N.P. 790	3R : 1S
7.	N.P. 710 × N.P. 790	N.P. 790	3R : 1S
8.	N.P. 781 × N.P. 790	N.P. 790	3R : 1S
9.	Pb. C. 281 × N.P. 790	N.P. 790	61S : 3R
10.	Pb. C. 591 × N.P. 790	N.P. 790	61S : 3R
11.	Pb. C. 518 × N.P. 790	N.P. 790	61S : 3R
12.	Pb. C. 273 × N.P. 790	N.P. 790	61S : 3R
13.	N.P. 775 × N.P. 790	N.P. 790	13S : 3R
14.	N.P. 710 × Kenya 184 P. 2. A. I. F.	Kenya 184. P.2. A.I.F.	15S : 1R
15.	Pb. C. 281 × Kenya 184 P. 2. A. I. F.	A.I.F.	15S : 1R
16.	Pb. C. 281 × Gaza	Gaza	15S : 1R
17.	N.P. 710 × Gaza	Gaza	15S : 1R
18.	N.P. 718 × Gaza	Gaza	15S : 1R
19.	Pb. C. 591 × Gaza	Gaza	63S : 1R
	B. Brown rust		
1.	N.P. 789 × Frondoso	Frondoso	9R : 7S
2.	Pb. C. 591 × Frontiera	Frontiera	3S : 1R
3.	N.P. 710 × Frontiera	Frontiera	3S : 1R
4.	N P. 710 × La Prevision	La Prevision	15S : 1R
5.	N.P. 165 × E. 871	E. 871	15S : 1R
6.	N P. 718 × E. 871	E. 871	15S : 1R
7.	Pb. C. 281 × E. 871	E. 871	15S : 1R
8.	Pb. C. 281 × Gaza	Gaza	3S : 1R
9.	Pb. C. 591 × Gaza	Gaza	3S : 1R
10.	N.P. 710 × Gaza	Gaza	15S : 1R
11.	N.P. 718 × Gaza	Gaza	15S : 1R

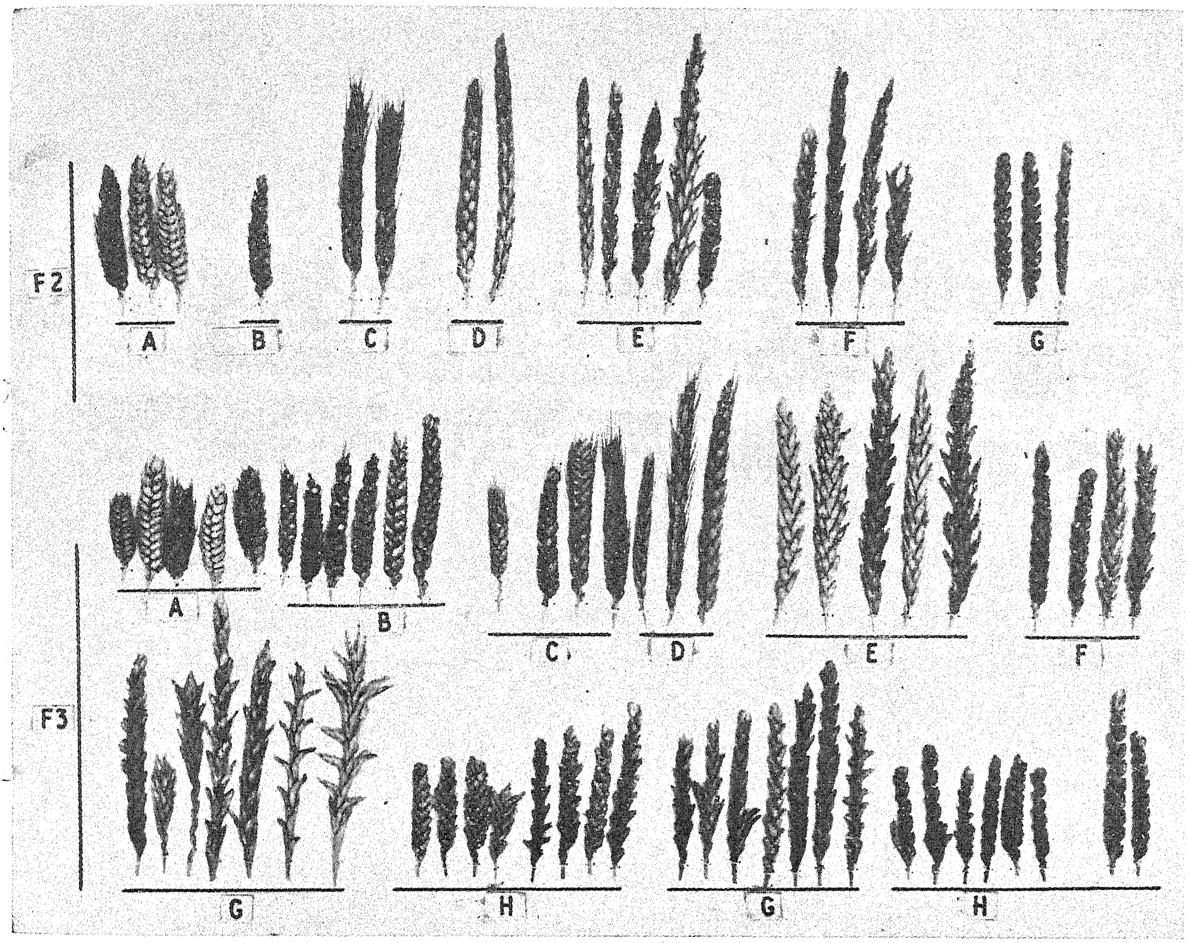


PLATE 24. Ear types in F_2 and F_3 of *T. vavilovi* × *T. sphaerococcum*

A, *sphaerococcum* like; B, *sphaerococcum* like (spelt); C, *vulgare* like; D, intermediate (spelt); E, *vavilovi* like (pseudo-branching); F, *vavilovi* like with extra glume and suppressed 'branching'; G, *sphaerococcum* like, spelted with extra glume and suppressed 'branching'; H, *sphaerococcum* like (spelted, branched and extra glume).

(*After* Singh *et al.*, 1957; by courtesy of Editor, *Agronomy Journal*)

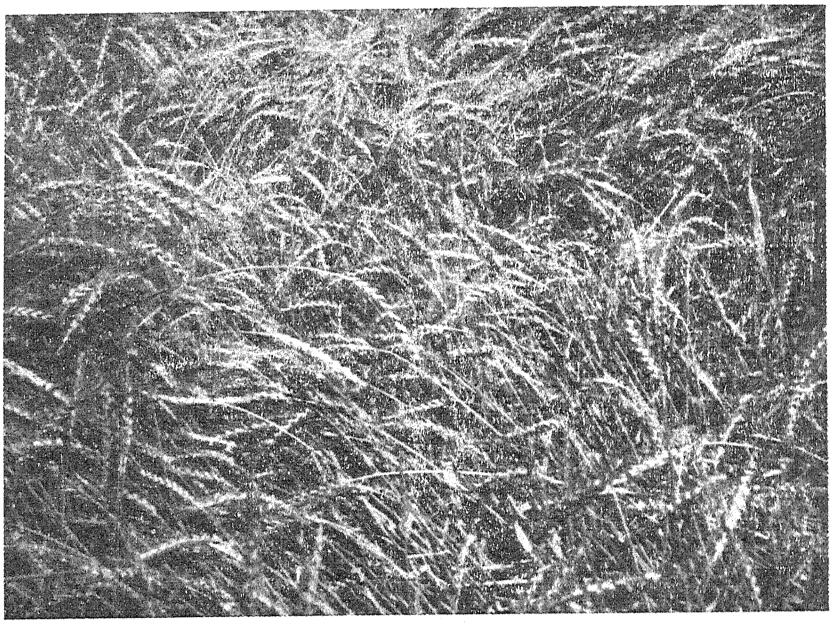


PLATE 25. A tall wheat variety grown with 40 lb. N/acre showing lodging

PLATE 26. S. 64, a two-gene dwarf developed in Mexico and found widely adapted in India

TABLE IV (*Contd.*)

Sl. No.	Cross	Resistant parent	Mode of segregation
	C. Yellow rust		
1.	N.P. 789 × Frondoso	Frondoso	57R : 7S
2.	N.P. 718 × Cometa Klein	Cometa Klein	3R : 1S
3.	Pb. C. 281 × Cometa Klein	Cometa Klein	3R : 1S
4.	Chinese White × N.P. 120	N.P. 120	3R : 1S
5.	N.P. 710 × N.P. 785	N.P. 785	13R : 3S
6.	N.P. 718 × N.P. 785	N.P. 785	13R : 3S
7.	N.P. 710 × La Prevision	La Prevision	13R : 3S

TABLE V. MODE OF INHERITANCE OF SEEDLING RESISTANCE TO DIFFERENT PHYSIOLOGIC RACES OF BLACK RUST

Sl. No.	Race/ biotype used	Cross	Resistant parent	Mode of segregation
1.	42	N.P. 775 × N.P. 790	N.P. 790	3R : 1S
2.	,,	Pb. C. 273 × N.P. 790	N.P. 790	3R : 1S
3.	,,	N.P. 710 × E. 1913	E. 1913	3R : 1S
4.	42B	N.P. 775 × N.P. 790	N.P. 790	3R : 1S
5.	,,	Pb. C. 273 × N.P. 790	N.P. 790	3R : 1S
6.	,,	N.P. 710 × E. 1913	E. 1913	3R : 1S
7.	,,	N.P. 710 × E. 581	E. 581	15R : 1S
8.	,,	N.P. 789 × E. 771	N.P. 789	3R : 1S
9.	,,	N.P. 790 × N.P. 710	N.P. 790	3R : 1S
10.	,,	Pb. C. 281 × N.P. 790	N.P. 790	3R : 1S
11.	,,	Pb. C. 591 × N.P. 790	N.P. 790	3R : 1S
12.	24	N.P. 710 × E. 1913	E. 1913	63R : 1S
13.	,,	N.P. 710 × N.P. 790	N.P. 790	15R : 1S
14.	,,	N.P. 718 × E. 572	E. 572	15R : 1S
15.	,,	N.P. 775 × N.P. 790	N.P. 790	15R : 1S
16.	,,	E. 871 × N.P. 165	E. 871	3R : 1S
17.	117	N.P. 710 × E. 1913	E. 1913	63R : 1S
18.	117	N.P. 775 × N.P. 790	N.P. 790	15R : 1S
19.	,,	N.P. 718 × E. 572	E. 572	15R : 1S

TABLE V (*Contd.*)

Sl. No.	Race/ biotype used	Cross	Resistant parent	Mode of segregation
20.	117	E. 871 × N.P. 165	E. 871	3R : 1S
21.	40	N.P. 710 × E. 1913	E. 1913	3R : 1S
22.	,,	N.P. 710 × N.P. 790	N.P. 790	3R : 1S
23.	,,	N.P. 718 × N.P. 790	N.P. 790	3R : 1S
24.	40	Pb. 518 × N.P. 790	N.P. 790	3R : 1S
25.	75	N.P. 710 × E. 1913	E. 1913	15R : 1S
26.	,,	Pb. C. 273 × N.P. 790	N.P. 790	15R : 1S
27.	,,	Pb. C. 281 × N.P. 790	N.P. 790	15R : 1S
28.	,,	Pb. C. 591 × N.P. 790	N.P. 790	15R : 1S
29.	,,	N.P. 790 × N.P. 710	N.P. 790	15R : 1S
30.	,,	N.P. 790 × N.P. 775	N.P. 790	15R : 1S
31.	,,	E. 952 × Pb. C. 518	E. 952	1R : 3S
32.	15	E. 871 × N.P. 718	E. 871	3R : 1S
33.	,,	E. 952 × Pb. C. 518	E. 952	3R : 1S
34.	21	N.P. 718 × E. 871	E. 871	3R : 1S
35.	,,	E. 952 × Pb. C. 518	E. 952	1R : 3S
36.	,,	N.P. 710 × E. 581	E. 581	15R : 1S
37.	,,	Pb. C. 281 × N.P. 790	N.P. 790	3R : 1S
38.	,,	Pb. C. 518 × N.P. 790	N.P. 790	3R : 1S
39.	15C	N.P. 710 × E. 1913	E. 1913	3R : 1S
40.	,,	Pb. C. 273 × N.P. 790	N.P. 790	15S : 1R
41.	15C	Pb. C. 518 × N.P. 790	N.P. 790	15S : 1R
42.	15C (colour mutant)	N.P. 710 × E. 1913	E. 1913	3R : 1S
43.	,,	Pb. C. 281 × N.P. 790	N.P. 790	3S : 1R
44.	,,	Pb. C. 273 × N.P. 790	N.P. 790	15S : 1R
45.	,,	Pb. C. 518 × N.P. 790	N.P. 790	15S : 1R
46.	21A	N.P. 710 × E. 581	E. 581	3R : 1S
47.	,,	Pb. C. 518 × N.P. 790	N.P. 790	3R : 1S
48.	,,	N.P. 718 × N.P. 790	N.P. 790	3R : 1S

TABLE V (*Contd.*)

Sl. No.	Race/ biotype used	Cross	Resistant parent	Mode of segregation
49.	21A	E. 2842 × Pb. C. 281	E. 2842	3R : 1S
50.	34	N.P. 710 × E. 581	E. 581	3R : 1S
51.	,,	Pb. C. 518 × N.P. 790	N.P. 790	3R : 1S
52.	,,	N.P. 718 × N.P. 790	N.P. 790	3R : 1S

made (Bansal, 1960) to find out whether the same gene/genes govern reaction to different physiologic races, have indicated that the same gene which controlled resistance to race 42 of black rust also controlled resistance to biotype 42B in crosses of N.P. 790, Kenya 184-P.2.A.I.F. and E. 871 (Timstein derivative). Similarly, one factor in N.P. 790, E. 871 and Kenya 184-P.2.A.I.F. was found to govern seedling resistance to a group of stem rust races and biotypes consisting of 34, 21, 21A and 15.

Inheritance of seedling resistance to races 13 and H of yellow rust and race 10 of brown rust was studied by Bahl and Kohli (1960). Resistance of Cometa Klein to the yellow rust races was governed by two complementary factors while the resistance of Frontiera and La Prevision to the brown rust race was governed by three factors.

Monosomic analysis carried out by Singh and Swaminathan (1959) in Chinese Spring monosomics × Cometa Klein indicated that Cometa Klein carried two recessive factors located on chromosomes 4A and 6A, which controlled resistance to race H and one recessive gene on chromosome 15A for resistance to race 13 of yellow rust. Similarly, resistance to race 15C of stem rust in the variety N.P. 790 was found to be governed by two recessive duplicate factors located on chromosomes 1A and 2A. Resistance to race 21 of the same rust was found to be governed by a single factor located on chromosome 3D (Singh and Swaminathan, 1960).

Association between rust resistance and other characters. Attempts have been made in India, as elsewhere, to find out whether field resistance to rusts was associated with any of the easily observable morphological characters (Sen and Joshi, 1955; Ghosh *et al.*, 1958; Sikka *et al.*, 1961 a, b; Prasad and Rao, unpub., 1959). Rust resistance was observed to be inherited independently of all the characters studied.

Conclusion. The salient features on the genetics of resistance to the different rusts, at both seedling and adult plant stages considered above, may be summarized as follows:

1. Several independent factors control resistance and susceptibility to rusts.
2. Resistance is sometimes recessive and sometimes dominant, the situation varying with the varieties used.
3. In interspecific crosses involving *T. durum* (resistant) and *T. aestivum* (susceptible) the F_1 plants were always susceptible, subsequent generations giving either monofactorial or duplicate-factor segregation.

4. In a majority of cases there is a positive correlation between resistance at the seedling stage and at the adult stage. However, sometimes plants found to be resistant in seedling tests may succumb to the disease at the adult stage and *vice versa*. Seedling and adult plant reaction may be governed by different genes but there may be linkage between the two.
5. It would appear that resistance to rusts in wheat is of a very complex nature, being controlled by two primary variables. A number of distinct genes in the fungus probably control its parasitic property which is effective only on certain host varieties, while within the host varieties there is another series of genes each of which controls independently resistance or susceptibility to one or more of the distinct gene-controlled parasitic properties of the pathogen. The assumption of the presence of inhibitors in crosses where the F_1 between a resistant and susceptible parent becomes susceptible explains satisfactorily the differential expressibility of the F_1 from different crosses with reference to resistance. The inhibitors again will be specific to particular races of the pathogen. Thus, a susceptible parent may carry factors for resistance to one or more strains of the fungus, which may not become apparent until the inhibitor is removed. For example, in the cross Pb.C. 591 (susceptible) and N.P. 790 (resistant) the F_1 is susceptible to race 15C of black rust. When, however, races 21 and 42 are used, the F_1 is resistant and duplicate-factor ratios are obtained, thereby suggesting that Pb.C. 591 carried factors for resistance to some races which, however, are revealed only in a hybrid genetic background. Monosomic analysis will be of great help in locating the chromosomes on which the genes, both conferring resistance and causing inhibition of expression of resistance, are located.
6. In the light of all the data on rust resistance, obtained in intra- and interspecific crosses, it would seem that a more intensive study of the mechanism of resistance and susceptibility in the plant is essential before a satisfactory genetical explanation can be offered. While we know nothing about the chemical nature of rust resistance, it is obvious that no simple factor like the presence of toxic materials, such as the phenols, in the resistant host cells could explain it. It seems likely that the availability of highly elaborated growth factors, such as vitamins, polypeptides, proteins and suitable combinations of enzymes, is necessary for the growth of rusts in the cells of wheat. Resistant cells may lack only one such component and the susceptible cells may possess all the requirements. Viewed in this light, the inhibitory factors referred to earlier may cause the synthesis of a substance needed for fungus growth, but normally lacking in the resistant plants. In cases where resistance is dominant, the susceptible parent does not help to synthesize the required substance in the hybrid, even though in its own complement such a substance is obviously synthesized. Physiological races may differ only in the requirement of one component. The complexity of this situation needs clear biochemical elucidation, which can be achieved only by the type of approach which has yielded such fruitful results in lower organisms like *Neurospora* (Pal and Sikka, 1957).

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V

CYTOGENETICS IN RELATION TO WHEAT BREEDING

The genome approach. The genome concept, while obviously an over-simplification of the natural and precise relations, has greatly aided the wheat breeder in planning his programme. Following the suggestion of McFadden and Sears that the best way of transferring desirable characters from species belonging to all the three allied genera to the cultivated bread wheats would be to make crosses in the appropriate genomic combinations, much work has been done to utilize the potentialities of intergeneric and interspecific hybridization in wheat improvement. Extensive work carried out at the Cambridge Plant Breeding Institute has shown that resistance to all the rusts possessed by *Aegilops caudata* can be transferred to bread wheat through proper crosses.

At the Indian Agricultural Research Institute amphidiploids of *T. dicoccum* × *T. monococcum*, *T. timopheevi* × *T. monococcum* and *T. timopheevi* × *T. durum* have been synthesized and used in breeding work. It has, however, been found that hybrids between 42-chromosome amphidiploids and 6x wheats do not strictly show the type of chromosome pairing at meiosis expected from their genomic constitution. This is because the differentiation of the different genomes is more relative than absolute. Work on the application of the genome approach in wheat breeding has also been in progress at the Laboratory of the Maharashtra Association for the Cultivation of Science, Poona, under a scheme sponsored by the Indian Council of Agricultural Research (Anon., 1960-61). A collection of species, ecotypes and races of *Triticum* and *Agropyron* has been built up. All species with desirable attributes have been crossed with the cultivated Indian *durum* and *dicoccum* wheats. Some crosses like *T. dicoccum* × *T. timopheevi*, *T. durum* × *T. persicum* and *T. dicoccoides* × *T. timopheevi* yielded highly sterile hybrids, and in such cases the F_1 plants have been backcrossed to the cultivated parent. Some promising selections have been made from the F_6 and F_7 progenies of *dimococcum* (amphidiploid *T. dicoccum* × *T. monococcum*). Similar AAAABB combinations are being synthesized with other emmer wheats with a view to crossing them with diploid *Agropyron* species. The species *T. aethiopicum* [= *T. abyssinicum* (Vav.) Flaksb.] has been found to possess resistance to almost all the prevailing races of black rust at Mahabaleshwar in seedling tests. This species has been crossed with some Indian strains of *durum* and *dicoccum* and the segregating progenies are being studied. Cytological studies have been carried out in some of the sterile interspecific and intraspecific hybrids and it has been found that various abnormalities occur in such plants during meiosis in microsporocytes.

Use of triploid and pentaploid hybrids in wheat breeding. Interspecific crosses between *T. aestivum* and *T. durum* and *T. dicoccum* have been attempted by

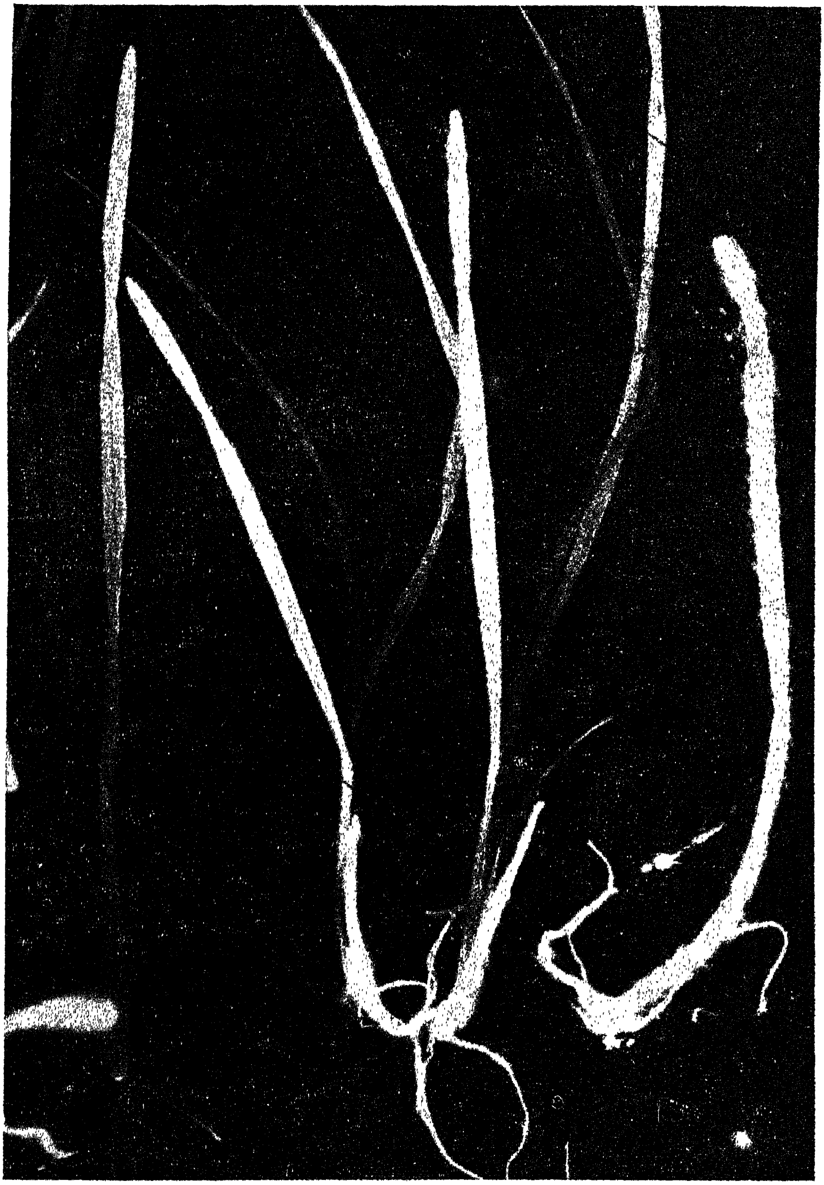

PLATE 27. Autoradiograph of wheat seedlings treated with P^{32}
(*Source :* Cytogenetics Section, Division of Botany, I.A.R.I.)

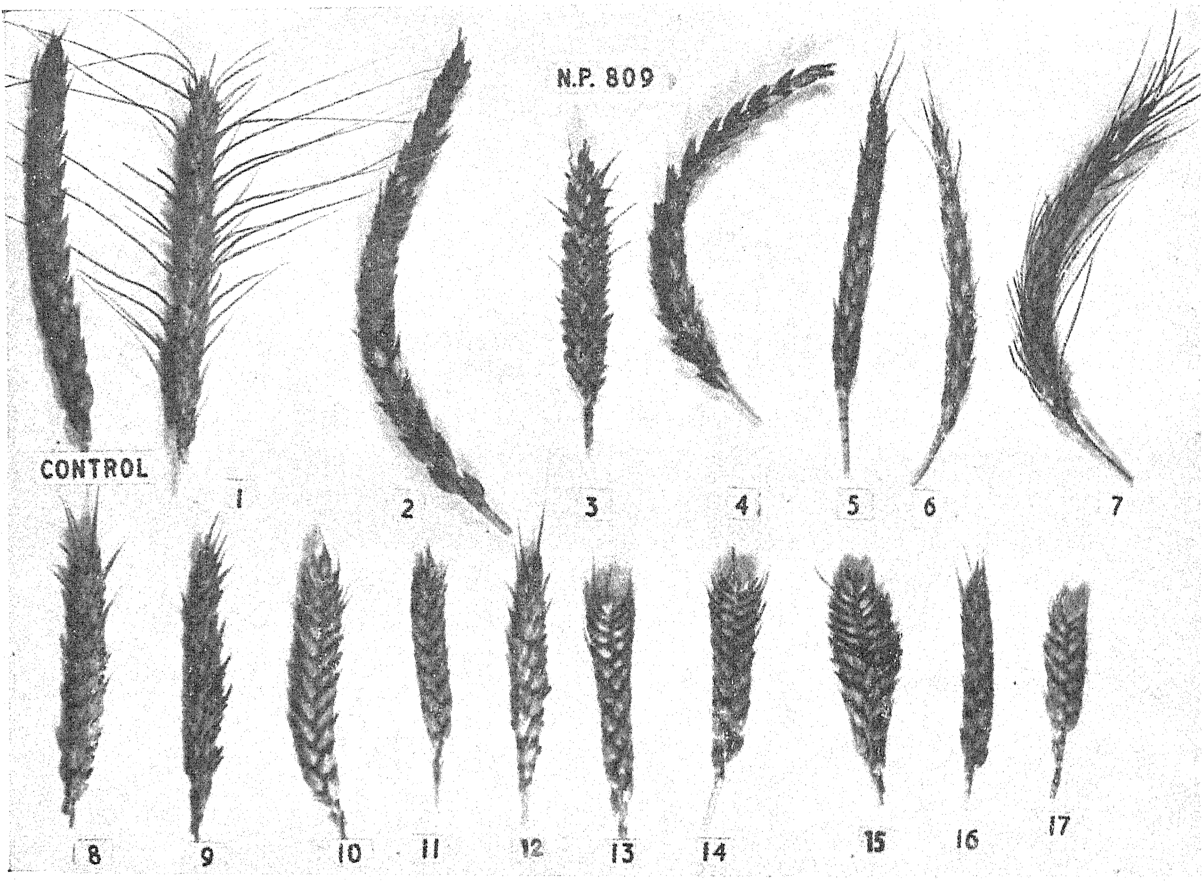

PLATE 28. Variability in ear characters induced by radiation (N.P. 809)
(*Source :* Cytogenetics Section, Division of Botany, I.A.R.I.

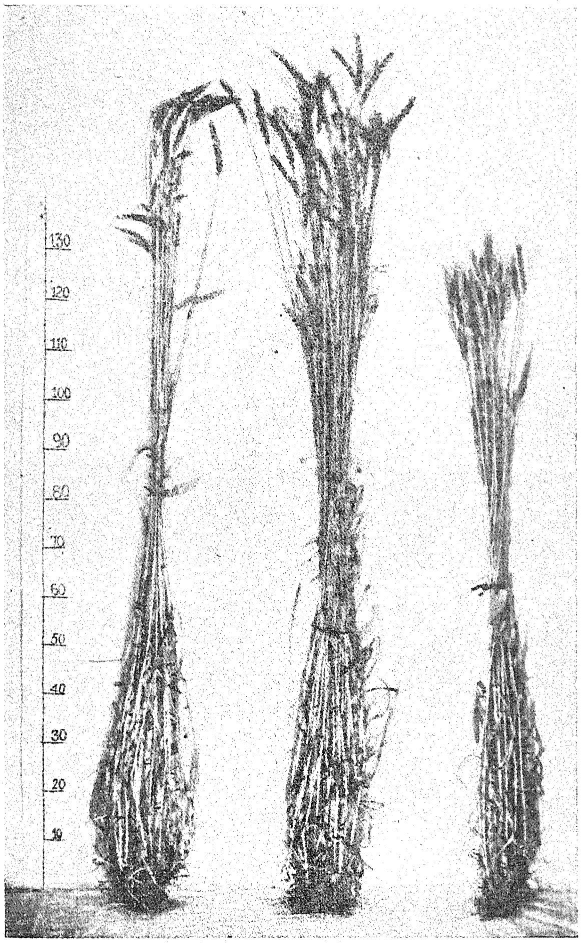

PLATE 29. Mutations induced in N.P. 809 by P^{32} treatment

Left to Right: control; fully bearded; fully bearded with short, stiff straw.

(*Source:* Cytogenetics Section, Division of Botany, I.A.R.I.)

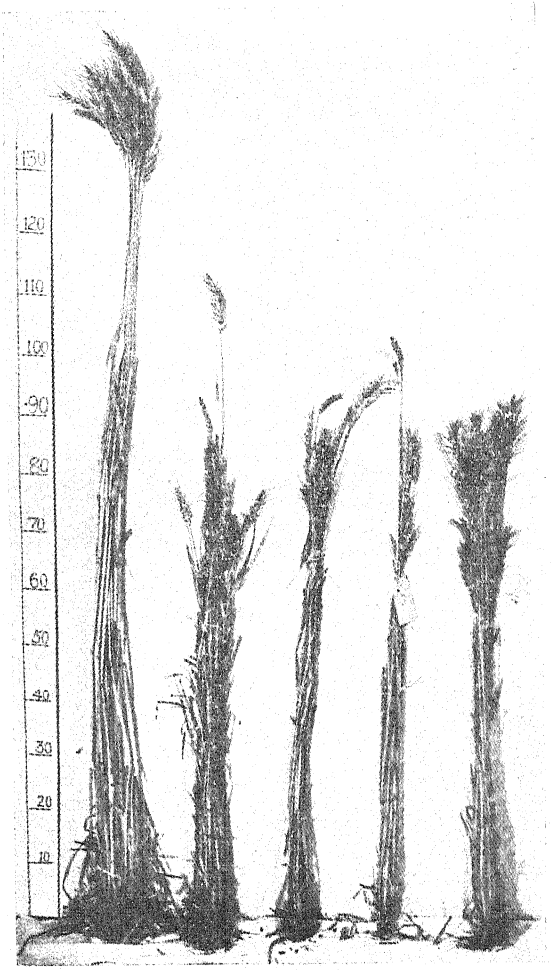

PLATE 30. A range of short- and stiff-strawed mutants in C. 591. Normal C. 591 is on the left

(*Source:* Cytogenetics Section, Division of Botany, I.A.R.I.)

several workers in India. Certain economically important wheat varieties, such as Ao. 90 in Madhya Pradesh, and *Bansipalli* and Niphad-4 in Bombay, have been evolved from such crosses. At the Indian Agricultural Research Institute, numerous pentaploid hybrids have been produced and studied both genetically and cytologically. A whole range of variation occurs in the pentaploid derivatives and individuals with euploid chromosome numbers appear to be the only stable combinations. Unless one works with large populations the possibility of evolving 42-chromosome types having the rust resistance of the tetraploids and the agronomic characteristics of *aestivum*, from the pentaploid hybrids, is rather low. Cytogenetic data also indicate that it may not be possible to obtain true-breeding viable combinations with chromosome numbers other than 28 or 42.

The importance of growing large populations is evident from the breeding work of Harrington and Smith (1929), Goulden (1929) and McFadden (1930). It is of interest to record that when in the late 1920's there was no resistant variety available and the rust epidemics were becoming very serious, McFadden produced a resistant strain from an emmer × *aestivum* cross and gave the name ' Hope ' to this line. This variety as well as Marquillo, a derivative of the cross Marquis × Iumillo (*durum*) made at the University of Minnesota, have been extensively used as parents in breeding work by wheat workers all over the world.

Among other examples of genetic transfer of characters through interspecific hybridization, mention may be made of the work of Allard and Shands (1954) who succeeded in transferring the stem rust and mildew resistance of *T. timopheevi* to bread wheat. Recently, Ohlendorf (1957) has also extracted fairly stable lines with resistance to mildew, leaf and stripe rust from the *timopheevi* parent in crosses between *T. timopheevi* and several bread wheat varieties. From these studies, it appears that: (a) if the transfer of characters occurred as a result of gene exchange between homologous chromosomes or chromosome segments, no cytogenetic or breeding complications will be encountered; (b) if it resulted from translocation involving non-homologous segments, the alien segment may cause pairing difficulties and also lead to complications in the breeding programme; and (c) if the transfer resulted from the substitution of a whole chromosome, the future breeding work would depend on whether or not the transferred chromosome carries genes responsible for undesirable traits. There are undoubtedly many unexplored possibilities of transferring not only disease resistance but also characters of agronomic importance from the primitive to cultivated wheats (Pal, 1951). At the Cambridge Plant Breeding Institute, some selections which are agronomically very promising have been obtained from the cross (amphidiploid *T. aegilopoides* × *T. persicum*) × *T. aestivum*.

Technique for chromosome doubling in *Triticum* species. Bell (1950) carried out a detailed investigation on various methods of colchicine application in wheat species and hybrids and found that the most successful method of application is capping cut-back tillers with a small glass phial containing 0·1 to 0·3 per cent colchicine.

Intergeneric hybridization. The possibility of introducing valuable characters into wheat from related genera has, since long, attracted the attention of the wheat breeder. Hybridization has been successful between various species of *Triticum* and species of the genera *Secale*, *Aegilops*, *Haynaldia*, *Agropyron* and *Elymus*.

There are also reports of hybridization with *Hordeum* but these lack confirmation. Some of the important results obtained with intergeneric hybrids are summarized below.

(a) *Wheat-Rye hybrids:* Hybrids between wheat and rye have been known since the beginning of the present century. These have been of interest primarily from the point of view of combining the winter hardiness and ability to grow in sandy soils of rye with the good baking quality of wheat. The *Triticale* strains so far produced are disappointing and Müntzing (1956) showed that this is due to the degeneration of the rye genome as a result of the self-pollinating nature of rye-wheat (rye is predominantly cross-pollinated and wheat is self-pollinated). Attempts are, hence, being made in Sweden to evolve *Triticale* strains from carefully selected rye parents which are able to withstand inbreeding. At the Indian Agricultural Research Institute, rye-wheat strains have been synthesized from several bread wheat strains and Assam rye. These strains have bold and large ears but are highly sterile. Pissarev and Shilkina (1955) reported that the application of boron in the form of foliar sprays improved seed development in *Triticale,* and at the Indian Agricultural Research Institute also it has been found that boron sprays (0·5 per cent boric acid) help in both seed setting and seed filling.

The D genome of wheat, as pointed out earlier, is derived from *Aegilops squarrosa,* a species which would not be chosen by most plant breeders as a parent in a breeding programme. Hence, attempts are being made by workers in Canada and Spain to replace the D genome with an entirely new set of seven chromosomes. They have obtained very vigorous amphidiploids between tetraploid wheat and rye and these 42-chromosome rye-wheats offer promise for cultivation in marginal environments where rye is, at present, the only suitable cereal crop (Sanchez-Monge, 1959).

(b) *Wheat-*Aegilops *hybrids:* Characters of *Aegilops* species that would be of value if these could be incorporated into wheat are resistance to black, brown and yellow rusts and to insect damage as also winter hardiness (McFadden and Sears, 1947). Hybrids between members of the genera *Aegilops* and *Triticum* can be obtained fairly readily but instances of plant breeding achievements through such hybridizations are few. Coffey (1956) reported success in transferring the stem-rust resistance of *Ae. speltoides* to hexaploid wheat. The amphidiploid *T. dicoccoides* × *Ae. speltoides* was crossed to *T. aestivum* and a resistant derivative of this was crossed with natural and synthetic *T. spelta.* The transfer was apparently accomplished by direct gene exchange involving homology of the *speltoides* chromosome, carrying the resistance, with a chromosome of the wheat complement.

The transfer of the leaf-rust resistance from *Ae. umbellulata,* a diploid species with practically no homology with any of the chromosome sets of bread wheat, was achieved by Sears (1956) by using an entirely new technique. He first added the chromosome of *Ae. umbellulata* carrying the gene for resistance to wheat and subsequently got, by means of irradiation, the segment with the desired locus translocated into a wheat chromosome. This is a type of change which one may never expect to occur in nature and serves as a remarkable demonstration of the impact of modern cytogenetical techniques in breeding work (Pal, 1958).

A great deal of interest has centred around what are commonly called

Aegilotriticums. These are for the most part naturally occurring or artificially produced amphiploids involving various species of wheat and *Aegilops.* Although they have valuable characters, nothing of practical value has so far been obtained from them. Probably some useful gene transfers may be effected in the future by using radiation-induced translocation techniques.

(c) *Wheat-*Agropyron *hybrids:* In the first three decades of this century, great expectations prevailed among wheat breeders as to the possibility of transferring disease resistance, drought resistance, increased winter hardiness and perennial habit from species of *Agropyron* to wheat. These hopes have not so far been realized, though in Russia Tsitsin has reported the successful production of perennial wheat strains from crosses between *Agropyron* and *Triticum* species.

A majority of the successful crosses with *Triticum* species has been made with species belonging to the couch-grass group, such as *A. elongatum, A. intermedium* and *A. tricophorum.* Most workers have attributed the high incidence of bivalent formation in *Triticum-Agropyron* crosses to true homology of one or more genomes of *Agropyron* with wheat. On this basis, success may be expected with regard to the transfer of genes from *Agropyron* but breeding results have been disappointing. Stebbins and Pun (1953) showed that the bivalents observed in F_1 of *Agropyron-Triticum* crosses arise from autosyndesis of the highly autopolyploid *Agropyron* used in these crosses. Hence, transfer of *Agropyron* characters through the normal process of gene exchange based on chromosome homology is unlikely. The amphidiploids may have, therefore, to be subjected to irradiation in order to effect the desired transfer of genetic material. Such a transfer involving a gene for stem-rust resistance from *Agropyron elongatum* to *T. aestivum* has been recently reported by Elliott (1957).

(d) *Hybrids with* Haynaldia *and* Elymus: Some species belonging to both *Haynaldia* and *Elymus* have many characters, particularly resistance to rusts, that would be valuable if they could be transferred to wheat. However, no results of practical value have been obtained since there is little homology between the chromosomes of these species and those of wheat.

Use of aneuploids. The use of monosomics and nullisomics in the study of wheat genetics has already been pointed out. Besides being of use in the location of genes on chromosomes, aneuploids are of use in developing chromosome substitution lines. The various steps involved in developing chromosome-deficient series in other varieties and in substituting individual chromosomes have been described by Sears (1953). Strains with additions and substitutions of alien chromosomes or parts of chromosomes may be of value directly or as sources for gene transfer by irradiation.

Use of embryo-culture and transplantation. Studies by Pissarev and Vinogradova (1944), and Hall (1954) showed that crossability of distantly related forms is increased if the embryo of the plant to be used as male is cultured on the endosperm of the female. There are many valuable forms related to wheat that have not yet been crossed with wheat. The embryo transplantation technique coupled with the *in vitro* culture of young embryos in suitable media may enable the wheat breeder to make new and interesting combinations with relatively distantly related species.

Induction and use of mutations. Soon after World War II, experiments on the peaceful uses of atomic energy attracted much interest and support. Sources of radiation became readily available and serious research on the use of radiations in plant breeding, which had until then been confined to Sweden, was commenced in many countries. As far as wheat is concerned, Gustafsson (1947) pointed out many years ago that when wheat seeds are irradiated, a mass-mutating effect sets in. The Swedish worker Mac Key clearly showed that the scepticism expressed by Stadler as to the possibilities for inducing mutations in polyploid plants was not applicable to bread wheat. In wheat, efforts in the United States centred around the induction of disease-resistant mutations. Ausemus *et al.* (1955) obtained a mutant in Lee similar to the control but with resistance to race 15B of stem rust. Konzak *et al.* (1956) obtained a mutant resistant to stripe rust in the variety Gabo by irradiation with thermal neutrons. Jenkins (1957) obtained a mutant in the *durum* variety, Stewart, resistant to race 15B of stem rust but this mutant had also altered morphological characters.

In India, work on the induction of mutations in bread wheat has been carried out in the earlier years by Ranjan (1940, 1941) and since 1955 at the Indian Agricultural Research Institute. The work at the I.A.R.I. was commenced primarily with two objectives: (a) the incorporation of a specific desirable attribute in an otherwise useful strain, and (b) the induction of new variability for traits controlled polygenically in highly bred strains. The varieties used were N.P. 797, N.P. 798, N.P. 799 and N.P. 809 (for incorporation of the character of awning) and Punjab C. 591 (for incorporation of resistance to rusts and loose smut). Fully awned mutants have been obtained in the four N.P. varieties and some of these mutants have outyielded the parent strains in yield trials conducted during 1957 and 1958. Some of these have given very encouraging performances in later years and one derived from N.P. 799 has been released as N.P. 836. The increased yield shown by the fully awned mutants in comparison with the parent strains seems to be caused by an increased photosynthetic surface provided by the awns. A wide range of mutagens such as fast and thermal neutrons, X-rays, P^{32}, S^{35}, ultraviolet rays, chemicals such as nitrogen mustard and groundnut and castor oils have been tried but there is so far no indication of any altered mutation spectrum caused by any of these mutagens (Pal *et al.*, 1958). The frequency of mutations, however, varies and radioisotopes such as S^{35} and P^{32} have been found to be particularly effective in inducing mutations in bread wheat (Table VIa, b).

The work done at the I.A.R.I., which probably represents the most detailed and critical research on the use of induced mutations in wheat breeding, has clearly shown that bread wheat is ideal for mutation studies since it appears to have a polysomic constitution as regards factors controlling several physiological and metabolic characters and a disomic genotype as regards many morphological traits. Thus, it exhibits the unique ability to survive gross intra- and intergenic changes and to yield a wide range of phenotypic variation (Plates 27—33) following irradiation. Another great advantage is that simple deletions of epistatic genes result in beneficial changes. Thus, deletion of the $\mathbf{B}_1$ or $\mathbf{B}_2$ locus leads to the origin of awn development in many bread wheat varieties which are just tipped and these fully awned mutants, as mentioned earlier, are of great economic interest, as exemplified by the release for cultivation of N.P. 836 derived from N.P. 799.

Among other mutations of practical interest isolated in bread wheat are stiff-strawed types and plants with better grain quality. Plants with a higher tiller

TABLE VIa. TYPES OF MUTATIONS IN M_2 PROGENIES (Data of Swaminathan and Natarajan, 1957)

Mutation	Number of mutants and % of total mutations					
	P^{32}	S^{35}	Fast neutrons	X-ray 11,000r	Ground-nut oil	Castor oil
Albina mutation	0	0	9 (39·51)	0	0	0
Short and stiff straw	1 (2·51)	1 (1·06)	0	4 (13· 8)	9 (20·45)	0
Fine straw	0	0	0	8 (27·06)	0	0
Speltoid	15 (38·65)	41 (43·63)	3 (13·17)	8 (27·60)	24 (54·54)	22 (66· 6)
Dense ear	5 (12·82)	17 (18·09)	3 (13·17)	4 (13· 8)	1 (2·27)	0
Lax ear	1 (2·51)	3 (3·18)	0	2 (6·90)	0	2 (6·06)
Awn characters	9 (23·07)	21 (22·33)	6 (26·34)	1 (3·45)	2 (4·54)	3 (9·09)
Others	8 (20·08)	11 (11·70)	2 (8·78)	2 (6·90)	8 (18·18)	6 (18·18)

TABLE VIb. MUTATION RATE (Data of Swaminathan and Natarajan, 1957)

Mutagens	Dosage	Plant progenies examined	Total mutations observed in M_2	Mutation rate per plant progeny (%)
P^{32}	5 μc per seed	92	39	42·4
S^{35}	As in above	100	94	94·0
X-ray	11,000r	60	29	48·3
	16,000r	43	23	53·5
	22,000r	27	6	22·2
Fast neutrons	10^9/cm.^{2}/ sec. for 3 hr.	107	23	21·5
Groundnut oil	Soaking for 24 hr.	29	44	155·5
Castor oil	As in above	54	33	61·0
Mustard oil	As in above	55	2	3·6

number and 1,000-grain weight have also been isolated in the irradiated progenies and the breeding behaviour of such plants is under investigation. The genetics of the established mutants has been studied; the fully awned mutants behave as single gene changes. The karyotypes of the mutants are similar to those of the parent strains and hence these mutations could have been caused by either cryptic deletions or intragenic changes (Natarajan *et al.*, 1958).

Contrary to the earlier view that the polyploid condition of bread wheat will be a handicap in mutation work, the results obtained at the I.A.R.I. have shown that viable mutations occur in large numbers in bread wheat. The relationship between polyploidy and radiosensitivity has been studied very critically using varieties of *T. monococcum*, *T. dicoccum* and *T. aestivum* as experimental material (Swaminathan, 1957; Swaminathan and Natarajan, 1957; Bhaskaran and Swaminathan, 1961). A comparison of the relative frequency of occurrence of viable and chlorophyll mutations is provided by the data in Table VII.

Table VII. Chlorophyll and viable mutation rates in 2x, 4x and 6x wheat

Material	Percentage of M_1 families segregating for mutation		
	Total of all mutations	Chlorophyll mutations	Viable mutations
T. monococcum	19·4	19·4	0
T. dicoccum	1·8	1·8	0
T. aestivum	39·9	2·1	37·8

It is, therefore, clear that variation caused by mutagens would be increased rather than decreased by polyploidy because of : (1) the viability of genotypes resulting from various chromosome irregularities which would be lethal in a diploid species, and (2) the increased number of chromosomes which may be affected. The work at the I.A.R.I. has, thus, helped in clarifying the theoretical principles involved in mutation breeding in bread wheat.

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VI

WHEAT BREEDING

The history of systematic attempts at wheat improvement is relatively recent. In the initial stages the improvement was carried out under private auspices in Europe and America through selection within local populations and introduction from other sources. In the selection work in the early part of the nineteenth century, the methods of individual plant selection and progeny testing were used by progressive farmers and private breeders such as Le Couteur in the Isle of Jersey, Patrick Shireff in Scotland, and subsequently by Hallet in England, Louis de Vilmorin in France and Hjalmar Nilsson in Sweden, and W. M. Hayes and M. A. Carleton in the U.S.A. The postulation of the pure-line theory by Johannsen (1903, 1909) provided the scientific basis for individual plant selection and progeny-row testing and the method has been exploited in several countries for the improvement of wheat and other crops.

Since the latter part of the nineteenth century the method of selection from the progeny of artificial crosses between varieties came into use. Some of the early wheat varieties bred by this method include Fulcaster by S. M. Schindel, Jones Fife and Red Wave by A. M. Jones, certain club wheat hybrids by W. J. Spillman, Ceres by L. R. Waldron, Ridit by E. F. Gaines, all in the U.S.A.; Marquis by C. E. Saunders and Garnet and Reward by L. H. Newman in Canada; Yeoman and Little Joss by R. H. Biffen and Holdfast by F. Engledow in England; and Federation by W. Farrer in Australia (Clark, 1936). Besides pure-line selection by the pedigree method, the back-cross technique developed by Harlan and Pope (1922), and Briggs (1930, 1958) has also been used in wheat improvement.

While the principal objective of the wheat-breeding work in these countries was the improvement of yield, emphasis was also laid on improvement of grain quality, standing ability, winter hardiness and resistance to drought. The toll taken by fungal diseases, such as the rusts and the smuts, focussed attention on the need for breeding disease-resistant wheat varieties. William Farrer did pioneering work in this direction in Australia as early as 1886 and developed rust-resistant wheat varieties through intervarietal hybridization. Monumental work was done on the cereal rusts by Eriksson (1894) in Sweden, and Stakman (1914), and Stakman and Piemeisel (1917) in the U.S.A., which led to the recognition of physiologic races in these organisms and, thus, laid the scientific basis for breeding for resistance to these diseases. Likewise, the demonstration by Biffen (1905) that resistance to rust was genetically controlled was an event of historic importance. The development of Marquillo from the cross Marquis × Iumillo (*durum*) at the University of Minnesota and the work of McFadden (1930) of the Department of Agriculture on the breeding of Hope and H. 44 from the cross of Marquis with Yaroslav emmer (*dicoccum*) are now well-known examples

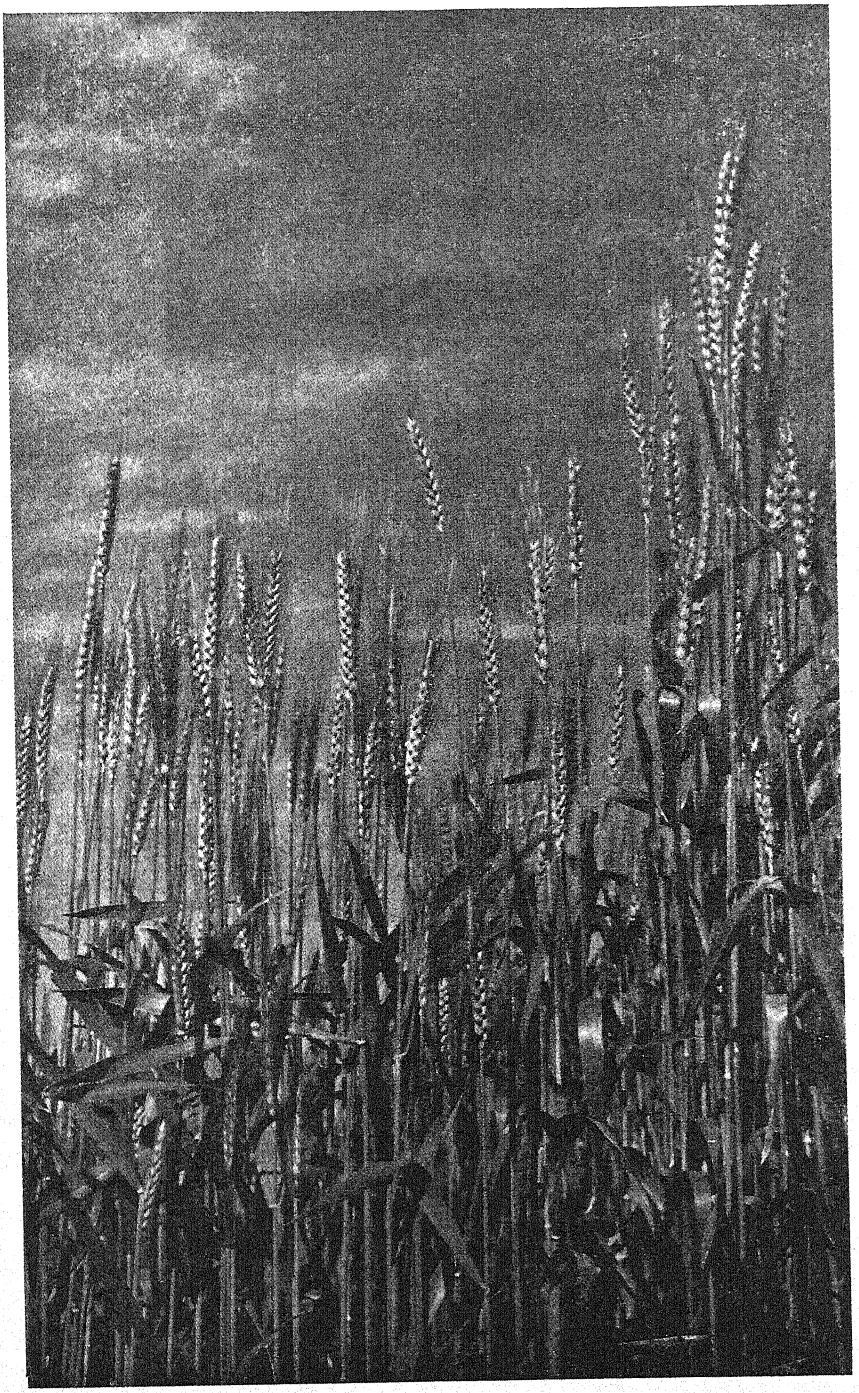

PLATE 31. Short-strawed, dense-eared plants (Left) and long-strawed, lax-eared plants (Right) of N.P. 809

(*Source :* Cytogenetics Section, Division of Botany, I.A.R.I.)

PLATE 32. A beardless mutant in C. 591

(*Source :* Cytogenetics Section, Division of Botany, I.A.R.I.)

of successful work in this direction. These wheats have constituted superior germ plasm with regard to genes for disease resistance, and they have been extensively used in further breeding for the control of stem rust and other diseases and the evolution of the renowned varieties such as Thatcher and New Thatch.

Work aimed at breeding varieties resistant to rust and other diseases is now in progress in most of the wheat-growing countries of the world. Extensive collections of wheat varieties have been built up at several centres and screened for reaction to diseases and pests (Reitz and Ward, 1958; Harrington, 1958). Detailed investigations have been carried out on the genetics of rust resistance (Ausemus, Watson, Shebeski, Knott, Sears, Pugsley, Unrau, Pal, Sikka, Rao and others) and this knowledge has proved very useful for breeding resistant varieties. Some interesting and new avenues of approach in combating rust have been indicated by the work of Watson and Singh (1952), who have suggested the incorporation of more than one gene, acting independently or in combination, governing rust resistance, and by the multi-line concept of Borlaug (1953, 1958).

The technique of distant hybridization has also been put to considerable use in wheat-breeding programmes. These have been dealt with in detail in the previous chapter. Examples have already been cited above on the utilization of the tetraploid *durum* and *dicoccum* wheats for the improvement of the hexaploid bread wheat. *Triticum timopheevi*, a disease-resistant species, has also been crossed with *T. durum* and *T. aestivum* (Allard and Shands, 1954). Intergeneric crosses have been obtained between *Triticum* species on the one hand and *Aegilops*, *Agropyron*, *Secale*, *Haynaldia* and *Elymus* on the other. Sears (1956) achieved an intergeneric transfer of leaf-rust resistance from *Aegilops umbellulata* while Coffey (1956) transferred stem-rust resistance from *Aegilops speltoides* to bread wheat. A similar transfer of streak-mosaic resistance from *Agropyron* to bread wheat has been reported by Larter and Elliott (1956). Interesting work on the utilization of species synthesized by distant crosses has also been in progress at the Plant Breeding Institute, Cambridge (*see* Riley and Bell, 1958). With a view to combining the best qualities of wheat and rye, hexaploid and octoploid *Triticale* have been synthesized (Müntzing, 1956; Sanchez-Monge, 1958; Shebeski, 1958). In the U.S.S.R., the production of perennial wheat and many other strains of improved wheat have been reported by Tsitsin and his associates from the crossing of cultivated wheat with *Agropyron* (Tsitsin, 1946).

In recent years, radioisotopes and other mutagenic agencies have been sought to be utilized in cytological and breeding investigations in India, Sweden, U.S.A., Canada and Japan and interesting results have been obtained.

Harrington (1952) has summarized the various procedures useful in the breeding of new varieties of wheat and other cereals. In the following pages a brief account is given of the wheat-breeding work carried out in India at the Indian Agricultural Research Institute and under the various State Departments of Agriculture.

WHEAT BREEDING IN INDIA

Although reference is made in the literature to some work in wheat selection having been carried out in India during the last quarter of the nineteenth century (Howard and Howard, 1910), wheat-improvement work on systematic lines commenced only during the first decade of the present century, when the Agricultural Research Institute (now Indian Agricultural Research Institute, New Delhi) was founded at Pusa, in north Bihar. Albert Howard and his wife, Gabrielle, commenced at Pusa, in 1906, their pioneering work in this field which resulted in the production of the early ' Pusa wheats ', such as Pusa 4, Pusa 6, Pusa 12, Pusa 52 and Pusa 80-5*; these gained reputation at home and abroad. Among the other early wheat breeders in India, mention may be made of T. Milne in the Punjab, H. M. Leake and Ram Prasad in Uttar Pradesh and Geoffrey Evans in Madhya Pradesh.

Wheat-growing regions, species and varieties. The varieties of wheat under commercial cultivation in India can be grouped under three species of *Triticum*, viz., *T. aestivum* (syn. *T. vulgare*), *T. durum* and *T. dicoccum*. *T. sphaerococcum*, a species native to north-western India, and at one time under cultivation in the Punjab, is now no longer grown (Singh, 1946, 1959). *T. durum* is now grown in parts of Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra and Mysore and covers approximately 10 per cent of the acreage under wheat in India. The rest of the area is under *T. aestivum*, except for small pockets comprising a few thousand acres planted to *T. dicoccum*, especially in the Nilgiri and Palni hills of Madras State and parts of Mysore, Andhra Pradesh, Maharashtra and Gujarat. The wheat-growing areas in India can be broadly divided into five regions: (i) northern region, comprising the plains of the Punjab, Rajasthan, Uttar Pradesh, Bihar and West Bengal (where *T. aestivum* is the predominant species under cultivation); (ii) central and western region, comprising the mixed *T. durum* and *T. aestivum* wheat-growing areas of Madhya Pradesh, the Bundelkhand area of Uttar Pradesh, Gujarat, and the *durum*-growing Kota region of Rajasthan; (iii) peninsular region, comprising the predominantly *T. durum* tracts in Maharashtra, Andhra Pradesh and Mysore; (iv) southern hilly region, representing the primarily *T. dicoccum* areas in the states of Mysore and Madras; and (v) the Himalayan region comprising the montane and submontane wheat-growing areas of Kashmir, the Punjab, Himachal Pradesh, Uttar Pradesh and West Bengal.

Wheat is grown in India mostly during the *rabi* (winter) season which extends from October to June, but as one goes from the northern hills down south through the northern plains to peninsular India, the season becomes shorter, and so is the case as one goes from the west to the east in the northern plains. In habit, Indian wheats correspond to the spring wheats of Europe and America (Pal, 1944). The hard amber types are generally preferred and secure a premium in the market over soft red, soft white, or hard red wheats.

Prior to the commencement of wheat improvement work in India, the wheat crop in general consisted of a mixture of different varieties. These mixtures, usually known as ' sorts ', were classified on the basis of grain characters, such as red or amber colour, hard or soft grain, etc., irrespective of their other botanical characters. It was

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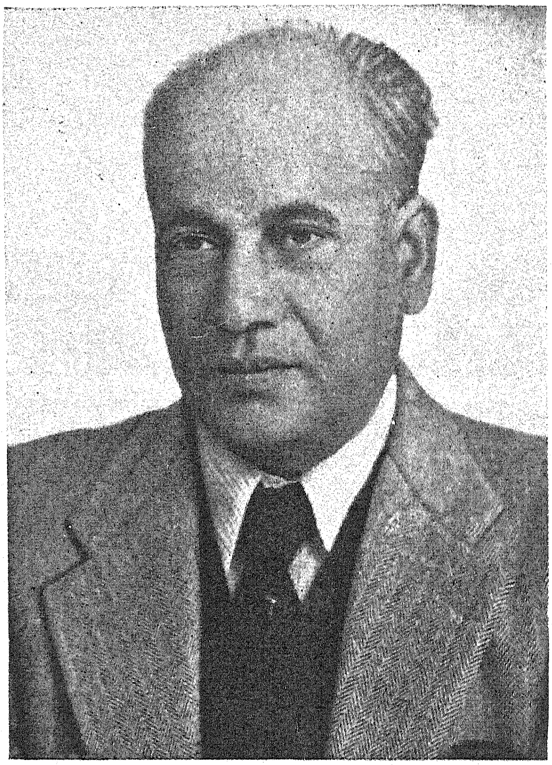
* The improved varieties of wheat and other crops bred at the Indian Agricultural Research Institute are designated by assigning numbers to them. When the Institute was located at Pusa, the word ' Pusa ' was prefixed to the numbers which was used either *in extenso* or was abbreviated such as ' Pusa 4 ' or simply ' P. 4 '. After the Institute moved to New Delhi in 1936, the prefix was changed to ' Imperial Pusa ' and the varieties designated as ' I.P. 4 ', ' I.P. 52 ', etc. Since 1947 the words ' New Pusa ' (or ' N.P.') are being prefixed to numbers assigned to the improved varieties. While there has been a change in the prefix, the original numbers assigned to the varieties have not changed. Thus ' Pusa 4 ' (P. 4) which later became ' I.P. 4 ' is now designated as ' N.P. 4 '.

PLATE 35

Sir Albert Howard

Mrs G.L.C. Howard

Plate 36



Dr. B. P. Pal

Dr. M. S. Swaminathan

not uncommon for a cultivator to grow different botanically distinct varieties together in his fields as long as they were not different from each other in grain characters.

Prominent among these ' sorts ' were the *sharbati*, *dara*, *saphed pissi*, *chandausi*, Karachi Choice White, Hard Red Calcutta, *lal kanak*, *lal pissi*, etc., in the *aestivum* group; *haura*, *bansi*, *kathia*, *jalalia*, *jamali*, *gangajally*, *khandwa*, *malvi*, etc., in the *durum* group; and *khapli*, *popatia* and *samba* in the *dicoccum* group. Sometimes these wheats were given such local names as *dawat khani* (for feasts), *pakwani* (for sweet dishes), *dudia* (soft white-grained), *pivla* (amber and yellow-grained), *lalka* (red-grained), *potia* (mottled), etc. *Sharbati* wheat with its uniformly amber-coloured and hard grains was the choice wheat in the market, fetching a premium over the other ' sorts '. This was considered to be very good for *chapattee* making. *Dara* formed the food for the poorer classes because of its un-uniform, low-quality, small grains. *Saphed pissi*, with soft white grains, was under cultivation in Madhya Pradesh and certain districts of eastern Uttar Pradesh while *lal pissi* was predominantly grown in Uttar Pradesh. *Lal kanak* was common in the Punjab, where it was liked for its hard grain for certain fried preparations. Among the *durums*, *bansi* with its high-grade amber grains was considered to be very superior. This was mainly grown in the Malwa tract of Madhya Pradesh. *Baxi*, a synonym of *bansi*, was cultivated in Bombay. *Jalalia*, another bold-seeded amber type, was grown in Madhya Pradesh while *gangajally*, a similar type, was grown in Bengal. *Kathia* wheats, which are hard and generally red, were grown in Uttar Pradesh, Rajasthan and certain areas of Madhya Pradesh. The *dicoccum* types, viz., *khapli*, *samba* and *popatia*, were grown in Maharashtra, Madras, Mysore, Andhra Pradesh and Gujarat where they were liked for their hard flinty grains, which are either amber- or red-coloured.

The *sharbati* wheats and other white-grained types which were exported to foreign countries from Karachi port were commercially known as ' Karachi Choice White '. The wheats sent from Uttar Pradesh to the markets in Calcutta were referred to as *chandausi*. These wheats were often mixtures and used to fetch very low prices in the world markets. Yet, certain areas in the country were known for the production of wheats of good grain quality. As a result of wheat-breeding work carried out during the past six decades there has been a marked improvement in respect of the uniformity and good quality of the wheats grown commercially.

WHEAT-BREEDING PROBLEMS AND OBJECTIVES

(a) *Adaptability and yielding ability:* Perhaps the foremost among the problems and objectives of wheat breeding, or for that matter in the breeding of any crop, is the production of varieties or strains superior in yield performance when compared to the best among the previously existing varieties or strains. In India, the wheat crop is grown under a great diversity and range of soil and climatic conditions: on soils ranging from light to heavy, from deep to shallow, from poor to high in fertility, under varying conditions of soil and atmospheric drought or on soils having a sufficient moisture supply or under artificial irrigation and under a regime of heavy fertilizer dose to conditions of insufficient or no manuring. It is grown on the plains, in river valleys, on plateau land as well as in the hills up to an elevation as high as about ten thousand feet above mean sea-level; the length of the crop season varies from three and a half or four months to as much as seven to eight months and the winter ranges from mild to severe. Over a major part of the country, the rainfed wheat is dependent on the residuum of soil moisture left after the monsoon rains. The winter rains, if received, may be capricious and, in the northern plains as well as in peninsular India, the maturation of the crop has to be completed before the hot winds of summer commence. Even the irrigated and fertilized crop, which has its own obvious advantages, must mature before atmospheric drought sets in (Chinoy, 1947). Little wonder, therefore, that the acre yields of wheat in India are, on an average, rather poor, but where optimum conditions for plant growth and development are obtainable, high yields comparable to those in the major wheat-growing countries of the world can be secured. The breeder's objective is, therefore, to evolve such varieties as would give superior yields under these various conditions.

(b) *Breeding for resistance to drought and lodging:* One of the primary considerations in wheat breeding in India has been the development of early-maturing wheats, or at any rate varieties maturing within the optimum duration of time which is characteristic of a tract and which varies from tract to tract. Further, a substantial part of the wheat-growing area in India is unirrigated and is likely to remain so for a long time to come, despite the effort the country is making to bring larger and larger areas under irrigation. For such areas, the breeding of early-maturing, drought-tolerant or drought-resistant varieties is of great importance. On the other hand, the irrigated tracts offer great potentialities for the attainment of maximum crop yields and they, therefore, deserve to be fully exploited by the development of varieties which would respond very favourably, in terms of yield, to intensive irrigation and manuring. Even under these conditions an early-maturing variety offers an advantage, since it saves one or a few irrigations, provided, of course, there is no compromise on yield. An important factor to reckon with, when the crops are intensively irrigated and manured, is the possibility of damage to the crop due to lodging. While adjustments in cultural and manurial practices, especially in respect of nitrogen application, can be helpful in minimizing or preventing lodging, the breeding of lodging-resistant varieties would offer distinct advantage. Under the prevailing agricultural economy, the farmer considers the yield of straw per acre almost as important as yield of grain; and, hence, the breeding of 'dwarf' or short-strawed and, therefore, lodging-resistant varieties was not considered advisable in the past. In future attempts to develop such varieties, care ought to be taken that the decrease in plant height is compensated for, as much as possible, by such factors as increased tillering, which would secure a good yield of straw per acre.

(c) *Diseases:* The wheat crop in India is menaced by a number of diseases. It is estimated that, on an average, 10 per cent of the crop is lost to these diseases annually. Among the diseases, the rusts are the most important. These are of three kinds: the black or stem rust (*Puccinia graminis tritici*), the brown or leaf rust (*P. recondita*), and the yellow or stripe rust (*P. glumarum*). Next in importance is the loose smut (*Ustilago nuda*). The stinking smuts, also called the bunts, are met with only in the hills of northern India; they include the smooth-spored *Tilletia foetida* and the rough-spored *T. caries*. The powdery mildew (*Erisyphe graminis tritici*) is also found in the hills —both in the northern hills as well as in the hills of southern India. The Karnal bunt (*Neovossia indica*) as also the flag smut (*Urocystis tritici*), are found to attack the wheat crop in southern Punjab, northern Rajasthan, Delhi and western Uttar Pradesh. The leaf spot diseases caused by species of *Helminthosporium* and *Alternaria* are responsible for considerable damage in the states of Bihar, West Bengal, Maharashtra and Gujarat. The foot rots caused by *Helminthosporium* and some other fungi have been frequently reported from Rajasthan, Madhya Pradesh, Maharashtra and some other states. The *tundu* disease, in which a bacterium (*Corynebacterium tritici*) and a nematode (*Anguina tritici*) are associated, also takes a toll of the crop in western U.P., Delhi, southern Punjab and northern Rajasthan. In view of the above, it is necessary to breed for combined resistance for all the important diseases. The organization of the work of breeding varieties resistant to the important diseases is briefly described below.

(i) RUSTS: All the three rusts attack the wheat crop in the hills and plains of northern India and in the southern hills. It is, therefore, necessary to breed for these areas varieties combining resistance to all of them (Dastur and Pal, 1947). In central and peninsular India (Madhya Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Mysore), the black rust predominates but the brown rust also appears sporadically. In the states of West Bengal, Orissa and parts of Bihar, both black and brown rusts are equally important.

Knowledge regarding the annual recurrence of wheat rust and regarding the physiologic races of the three rusts occurring in India first became available in the early thirties of the present century as a result of the pioneering work of the late Dr. K. C. Mehta of the Agra University. Till to date, 13 races and 3 biotypes of black rust, 12 races of brown rust and 10 races of yellow rust have been reported. Thus, at present, the number of physiologic races which the wheat breeder in India has to contend with is relatively small, although it is possible that newer races and biotypes may be isolated in future as a result of intensification of the race-analysis work. It may be mentioned in this connection that as the area under rust-resistant varieties in the country increases, the picture regarding the preponderance of certain races or biotypes over the others is likely to change and new races and biotypes may be picked up. Thus, in India, as elsewhere, the fight against the rust is a perpetual one.

The establishment, in 1935, of the Wheat-Breeding Substation at Simla in the northern hills, under the Indian Agricultural Research Institute and financed by the Indian Council of Agricultural Research, was the first step taken in India in the direction of breeding of rust-resistant wheat varieties. It was felt that, since the rust inoculum infecting the crop in the northern wheat belt came from the northern hills the breeding and dissemination of rust-resistant wheat varieties in these hills would, to a great extent, minimize the hazards of the rusts in the northern plains. It was subsequently appreciated, however, that such a step may not be the full answer to the question for the following reasons: (1) even if fully rust-resistant varieties became available for the hills, it would be difficult to fully saturate these areas with such varieties owing to the difficult terrain and lack of inadequate communications; hence, self-sown volunteer plants of the local susceptible varieties could always serve as sources of inoculum; (2) barley and certain other grasses act as collateral hosts; and (3) certain areas in the northern hills, such as Nepal, are outside the political boundary of India and the growth of susceptible varieties there could always serve as a source of inoculum.

It was, therefore, considered necessary to enlarge the scope of the rust-control programme. A wheat-breeding station was established at Powerkheda in Madhya Pradesh in 1941 for breeding black-rust-resistant varieties; for carrying out the ancillary plant pathological work, a wheat rust research station was set up in 1942 at Mahabaleshwar in Bombay State (now in Maharashtra State). Both these stations, as also the breeding scheme commenced in 1943 at Niphad in Bombay State (now in Maharashtra), were jointly sponsored by the Indian Council of Agricultural Research on the one hand and the respective State Governments on the other. In 1949, the Indian Council of Agricultural Research sponsored the Coordinated Wheat Rust Control Scheme for further augmenting the wheat rust programme. Under this scheme, the breeding and mycological work at the Indian Agricultural Research Institute was further strengthened. For the breeding work, in addition to the station at Simla, five other centres were established under the Institute at New Delhi, Pusa (Bihar), Indore (Madhya Pradesh), Wellington (Nilgiri Hills, Madras State), and, subsequently, Bhowali (U.P. hills). The control of the Rust Research Laboratory at Simla was transferred to the Institute in 1951 and another centre for mycological work was located at Wellington. The breeding and mycological work at the Institute has now been placed on a permanent basis under the auspices of the Government of India. In the states, breeding stations were set up under this scheme, under the sponsorship of the Indian Council of Agricultural Research, at Gurdaspur in the Punjab, Durgapura in Rajasthan, Kanpur in Uttar Pradesh, Badnapur in Hyderabad (now in Maharashtra) and Kalyani in West Bengal, in addition to those previously located at Powerkheda, Niphad and Mahabaleshwar.

(ii) SMUTS: Breeding for loose smut resistance has so far been carried out at the Indian Agricultural Research Institute only and a number of smut-resistant strains have been evolved. Under a Second Five-Year Plan Scheme, breeding and mycological work was recently taken up at the Institute for the development of wheat varieties resistant to the hill bunts and the Karnal bunt. The investigations are being conducted at the substations of the Indian Agricultural Research Institute at Karnal (Punjab) and Simla.

(iii) OTHER DISEASES: The other wheat diseases mentioned earlier in this section have not yet received the attention of the Indian wheat breeders, even though their importance has been fully appreciated. As and when suitable techniques become available for the artificial creation of epiphytotics of these pathogens, the breeding work would be taken up.

(d) *Pests:* India is fortunately well placed with regard to insect pests of wheat since no serious pest on this crop is known in this country. Only termites or white-ants (*Microtermes obesi* and *Odontotermes obesus*) are known to cause certain damage to the wheat crop, especially in dry tracts. Galls or cockles, due to the nematode *Anguina tritici* have been reported from around Delhi and adjoining tracts. Certain other pests, like the grasshopper, the stem borer, the wheat aphid and the pale green bug, are known to attack wheat, but none of them have posed a serious problem. Consequently, breeding for insect resistance has not been attempted.

(e) *Grain quality:* From the standpoint of grain colour and texture, mainly wheats with soft white and amber hard grains are grown in India. Red-grained varieties were grown extensively until some decades ago but now they occupy relatively lesser area. As has already been mentioned, there is a preference for the amber, hard, lustrous grain, which fetches a premium in the market. In certain areas, however, such as in parts of Mysore, red-grained *durums* are liked by consumers. Howard and Howard

(1910) recorded that the red-grained varieties were considered to be more prolific as compared to the white-grained ones in respect of seed production and, hence, they were more competitive in the field. There is, however, no definite experimental proof to confirm this belief.

Towards the beginning of the present century, it was generally believed that the Indian wheats were not of a very good quality and, therefore, they fetched a lower price in the export market. But it was shown by the Howards that good-quality wheats were grown in certain areas and that if systematic selection work was carried out, superior-quality wheats could be evolved. This was borne out by the results achieved at the Indian Agricultural Research Institute as early as the first decade of this century.

In the earlier years of wheat breeding in India, there was no arrangement for carrying out technological tests on the milling and baking qualities of cereals. The samples had, therefore, to be sent to England for testing. Subsequently, a well-equipped cereal-testing laboratory was set up at Lyallpur (now in Pakistan). Recently, a scheme was put into operation at the Indian Agricultural Research Institute, under the Second Five-Year Plan, relating to researches on testing the milling, baking and *chapattee*-making qualities of wheat. A Cereal Research Laboratory, equipped on the most modern lines with milling, baking and cereal testing equipment has been set up at the Institute, and in this direction the Indo-U.S. Technical Cooperation Mission and the Rockefeller Foundation have given considerable assistance. It is expected that, with these facilities, systematic work will now be taken up in the country for the breeding of good-quality wheat varieties. Besides bread and *chapattee*-making, varieties suited for special purposes, such as pastry and biscuit-making and for use in breakfast cereal preparations, would also have to be bred.

(f) *Miscellaneous:* Besides the major objectives of wheat breeding outlined above, there are certain others which the Indian wheat breeder has to take into consideration. First, the Indian wheat grower generally prefers awned (fully bearded) wheats to awnless ones owing to the belief that the latter are more damaged by birds and other animals than the former. There is, however, no categorical experimental proof in support of this belief. But, presumably the awned varieties could be preferred for another reason, namely, that other things being equal, the awns would contribute to photosynthesis in the ear and, hence, to yield (Asana and Mani, 1950; Atkins and Norris, 1955). In the hills, however, awnless varieties are generally preferred because they are easier to thresh. Yet another ear character which deserves mention relates to free threshability. The ear should not be difficult to thresh, nor should it be so easy to thresh as to cause grain shattering before or during the harvest operations. Easy threshability offers particular advantage in areas where there is high atmospheric humidity at harvest time.

In breeding wheat varieties, certain special requirements are also required to be taken into consideration with the development of the water resources and increased production of fertilizers in the country, and also due to the drive for intensive cultivation. The new varieties should be such that they give maximum response to high-fertility conditions without lodging (Pal and Parthasarathy, 1948). In areas where wheat sowings are delayed owing to non-availability of irrigation water in time, or due to flooding caused by late rains, or when a wheat crop is required to be taken after late paddy, varieties suitable for late sowing have to be developed. In such areas, transplanting wheat has recently been recommended as a result of agronomical researches carried out at the Indian Agricultural Research Institute (Raheja and Mathur, 1959); it is recommended that wheat seedlings may be raised in nurseries which are sown in proper time and the seedlings transplanted when the land becomes available in the proper condition. Soil salinity has posed some difficult problems for crop cultivation in certain states, like Uttar Pradesh and Rajasthan, and the development of salinity-tolerant or salinity-resistant strains would be very useful. A wheat variety from Rajasthan, known as *kharchia*, is reported to possess tolerance to salinity (Bhatnagar and Murty, 1960). Breeding for frost resistance or for winter hardiness has never been a problem of wheat breeding in India, but in certain states, like Madhya Pradesh, acres after acres of the wheat crop can be severely damaged by air frost if it occurs when the varieties come into ear. For such areas it is advisable to develop frost-resistant varieties.

In certain states, such as Madhya Pradesh, Gujarat, Maharashtra and Mysore, a considerable proportion of the wheat area is planted to *durum*. Yet, in the wheat-breeding projects the improvement of these wheats did not receive much attention, except for some work carried out in the earlier years in Bombay State. The station located at Indore (Madhya Pradesh) under the Coordinated Wheat-Rust Control Scheme operating at the Indian Agricultural Research Institute, was established with the primary object of breeding rust-resistant *durums*. Recently, work on these lines has also progressed at Powerkheda in Madhya Pradesh and at Niphad in Maharashtra.

The Karnatak area, which was a part of the former Bombay State, is now merged with Mysore after the reorganization of states. The main wheat-growing districts of Karnatak are Dharwar, Bijapur and Belgaum. The bulk of the crop here is grown under rainfed conditions. Prior to 1942, the work on wheat in the Karnatak division consisted of district trials with the improved strains evolved at the Agricultural Research Station, Niphad. *Jaya* (*Bansipalli* 808) was found suitable for general cultivation in the tract because of its early maturity, which helped in escaping rust damage. This strain, however, did not suit the local taste and the need was felt for a red hard wheat, for which there is a good market, both for local consumption and export to Madras State. Accordingly, wheat-breeding work was taken up at Bijapur with the object of making selections in local wheat. Promising selections in local red hard wheat have been isolated. Work has been recently taken up at Annigeri (Dharwar district) and at Bailhongal (Belgaum district). The main problem of wheat improvement in the Karnatak is the development of a hard red wheat which is resistant to black rust. Accordingly, the promising selections at Bijapur, Annigeri and Bailhongal have been crossed with Gaza (*durum*). The derivatives of these crosses are now undergoing trials.

In certain areas, e.g., the Nilgiri Hills and parts of Mysore and Andhra Pradesh (Vaheeduddin, 1959; Yardi, 1957), there is a strong local preference for *dicoccum* wheat, despite its brittle rachis and hard-to-thresh spikelets, because this wheat is believed to possess grain characteristics suitable for some special dishes such as *uppumav*; it would be an advantage if free-threshing strains of *dicoccum* could be evolved by crossing this wheat with *durums* without adversely affecting the desirable grain characteristics of *dicoccum*. Work on these lines is in progress at the Wellington centre under the Indian Agricultural Research Institute.

Until recently a majority of the agricultural departments in India did not have a well-organized extension service and the work of pure seed production and distribution used to be carried out only in a few progressive states, through the agency of departmental farms and private registered growers. But these efforts have not been uniformly adequate, with the result that until a few years ago the percentage of wheat area under improved varieties, in the country as a whole, did not exceed about 40 per cent. Now the Centre as well as almost every state has a full-fledged extension department catering to the agricultural requirements of about 5,000 Blocks into which the country has been divided. A seed-multiplication programme has recently been drawn up by the Government of India with a view to making each Block self-sufficient in respect of pure seed production and supply. Under this programme, attention will be devoted first to the major food plants of the country, including wheat. One of the cardinal points under this project is to ensure that, as far as possible, a single improved variety of a crop, or only a few varieties, would be chosen for multiplication and distribution within the Block. It is also intended under this project to keep the number of varieties under each crop, chosen for multiplication and distribution in the entire country, as small as possible, so that multiplicity of varieties does not create problems of its own. In this context, it would be desirable to breed varieties with a wide range of adaptability so that each single variety covers as large a portion of the wheat-growing tract as possible.

A seed-testing and certification programme has been envisaged in this connection and a chain of seed-testing laboratories is being set up at a number of locations in the country.

EARLY WHEAT-BREEDING WORK

Howard and Howard (1910) made a mention in their book of the attempts made in the last quarter of the nineteenth century to produce ' pedigree seed ' of a number of selected wheat varieties, such as Muzaffarnagar white, Buxar white and the selected *pissi* wheats which had given better yield performances than the local mixtures. Large quantities of such ' pedigree seed ' are reported to have been distributed for cultivation. They also make a mention of the selection work carried out at Kanpur in 1880-81, of the attempt made in 1887 at Nagpur to produce pedigree *haura* wheat using the selection method adopted in England by Hallet in 1857, and of the work of selecting large and small ears and large and small seeds from the same ear carried out at Poona from 1903-1905. None of these methods yielded any permanent improvement.

Pure-line selection: As has been mentioned earlier, the Howards were the first to undertake in India wheat-breeding work on a systematic basis. In 1906 they commenced, both at Pusa in Bihar and Lyallpur in the Punjab (now in Pakistan), a system of selection from single plants which enabled them to produce several wheats of much greater value than the mixtures then in cultivation. Pusa 4, Pusa 6 and Pusa 12 (now N.P. 4, N.P. 6 and N.P. 12) are outstanding examples of the results achieved at Pusa through individual plant selection. Work on similar lines carried out at other centres resulted in the production of improved types, such as Type 9, Type 9D, Type 11 and Type 8A, at Lyallpur in the Punjab (Pakistan), C.13 (K.13) at Kanpur in Uttar Pradesh, and Ao.13 and Ao.90 at Nagpur in Madhya Pradesh.

Introductions: In the early records dealing with the wheat improvement work in India, reference to trials of exotic varieties are frequent. During the last quarter of the nineteenth century, various Canadian, American, English, Egyptian and Australian varieties (including Farrer's hybrids) as well as isolated samples from Palestine, Mexico and Russia were grown. However, these attempts at the introduction of the exotic wheats were largely unsuccessful because of the extreme lateness of the exotics under Indian conditions, as also due to their grain characters which were not acceptable to the farmers and the trade. In subsequent years, two Australian wheats, viz., Bena and Federation, were found to be reasonably promising and are reported to have been recommended for cultivation in the hilly areas of north-western India. During the early thirties of the present century some Italian wheats were tried in the hilly regions of Uttar Pradesh as a result of which Padova II was placed on the list of approved varieties of the Uttar Pradesh Department of Agriculture.

In connection with the project on the breeding of wheat varieties resistant to rust and other diseases, the Indian Agricultural Research Institute has built up a large collection comprising about 4,500 exotic wheat varieties. A majority of them have not been of direct commercial interest, but many have proved very useful as donors of resistance to rust and other diseases. Two wheats, one from Australia (Ridley) and the other from the U.S.A. (Timstein × 20/86 Sel. 1495A-1-31-2-1), gave encouraging performances. Ridley has done very well in the hilly tract of Himachal Pradesh, the Punjab, Uttar Pradesh and West Bengal (Pal and Singh, 1951; Pal and Sikka, 1956a,b) and large areas have been covered by this wheat in that region. The Timstein derivative did well in north Bihar, especially with regard to early maturity, high yield and rust resistance, but was not released for general cultivation owing to its unsatisfactory grain character. Incidentally, it is now understood that the Timstein derivative received from the U.S.A. originated from Australia and that the Timstein parent involved in the cross was a sister selection of Gabo and was not derived from the cross of the bread wheat, Steinwedel, with the tetraploid species, *T. timopheevi* (Professor W. M. Myers, Univ. Minnesota, U.S.A., personal communication).

Hybridization: The technique of hybridization in wheat is a simple one. The ear to be operated upon is selected at the stage when the anthers of the middle spikelets are fully grown and beginning to show a slight tinge of yellow, indicating that they will ripen on the following day. If the ear belongs to a dense or a compact variety, alternate spikelets are removed on both sides of the rachis, preferably by tearing them off with a forceps. The median florets of a dozen spikelets are then removed by pressing them outwards and pulling sharply downwards. In this way only the two outermost florets of each spikelet are allowed to remain. The remaining spikelets are completely removed. The florets are opened by gently pressing the apex of the palea or, if a bearded variety is used, by pressing outwards the previously cut-back awns, and the stamens are carefully removed. After emasculation the ear is normally covered with a glassine or butter-paper bag to prevent natural pollination by an undesired parent. Should an anther break during the operation, the spikelet is cut off. Pollination is effected by placing a freshly opened anther into the emasculated floret or dusting pollen either immediately, if the stigmatic lobes are receptive, or one or two days after

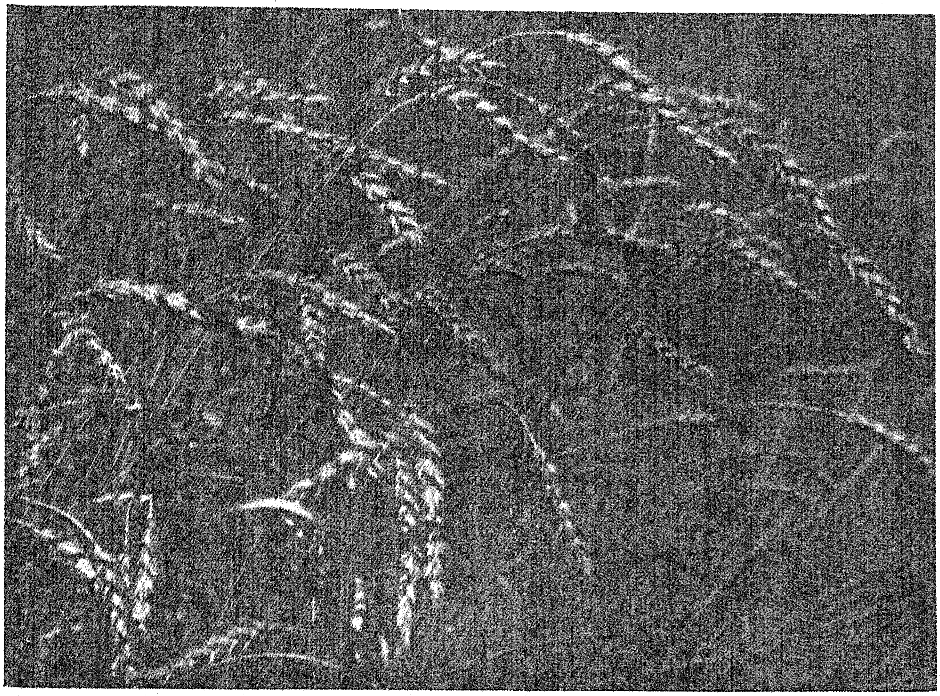


PLATE 42. N.P. 165

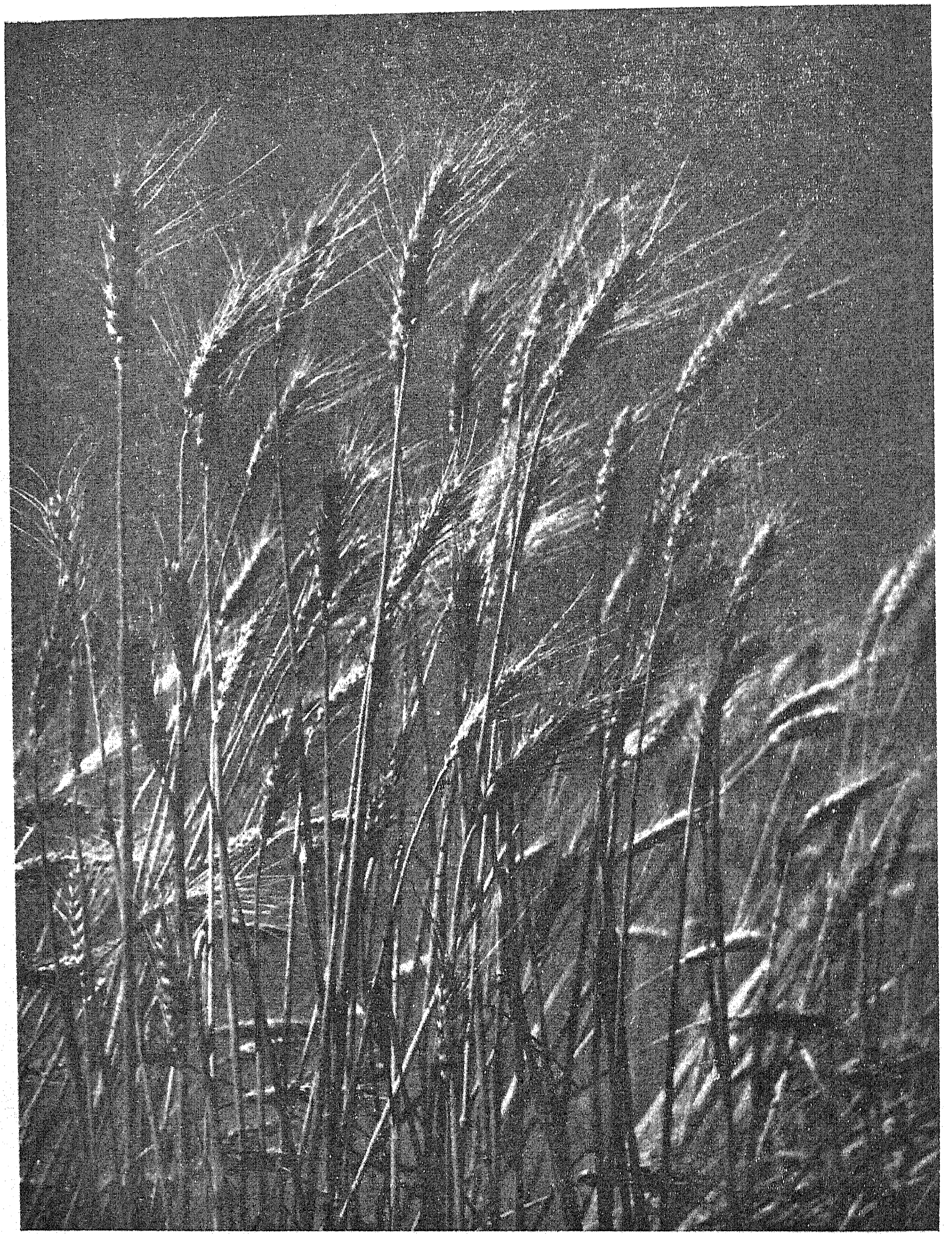


PLATE 43. N.P. 710

emasculation. Before making a fresh set of crosses, or in the event of a stamen from the mother plant breaking, the forceps are sterilized by dipping them into rectified spirit. The receptivity of the stigma often extends to a period of about a week. After pollination the ears are protected by means of glassine bags or butter-paper bags. The protecting bags may be removed a week after pollination or they may remain on the ears until the grain ripens. If the latter course is adopted the bags should be slit open at the base to allow the water, which accumulates as a result of transpiration, to escape.

The method of hybridization for wheat improvement has been used since the first decade of this century when the Howards took up their wheat-breeding work at Pusa. Since then several other Indian breeders have exploited this method for the production of improved varieties. In intervarietal hybridization the crosses have been made between Indian varieties, or between these varieties on the one hand and foreign varieties on the other. In this direction selection has been carried out by a majority of the breeders in the progenies of single crosses by using the orthodox pedigree method. Occasionally, as for instance in combining resistance to more than one rust, three-way or double crosses have been made. For introducing certain specific genes into the otherwise desirable commercial varieties, the back-cross technique has also been used. Interspecific hybridization has also been resorted to.

WHEAT BREEDING AT THE I.A.R.I. AND THE STATES

Indian Agricultural Research Institute

Early work: As mentioned earlier, systematic researches on wheat breeding in India first commenced at this Institute in 1906. Albert Howard and his associates, Gabrielle Howard and Abdul Rahman Khan, were the pioneers in this field. N.P. 4 (Plate 40), N.P. 6 and N.P. 12 (Plate 41) were among the first successful wheats evolved by them through pure-line selection in indigenous material. These wheats became popular in India as well as in some countries abroad, such as Australia, South Africa, Rhodesia and Hungary (Howard and Howard, 1910, 1928), where these were used either for commercial cultivation or as parents in hybridization. Some of the early Australian improved wheats, such as Puglu (Pusa 4 × Gluyas), Puora (Pusa 4 × Flora), Puseas (Pusa 4 × C.C.C.) and others, had Pusa wheats in their parentage, as is indicated by the first two letters, 'Pu', in the names given to these wheats (Wenholz *et al.*, 1940). N.P. 4, a selection from the local sort *mundia* (meaning awnless), was rated as one of the best quality wheats in the world. It won the first prize successively for four times from 1916 to 1920 in international grain exhibitions. This wheat was found to have a wide range of adaptability, being suitable for the North Indian plains, the hills of Kashmir and Jammu and for Uttar Pradesh, Gujarat and the Deccan tract of Maharashtra and some other parts of peninsular India. In New South Wales, Queensland and Western Australia, about 1·85 lakh acres were grown to this wheat even until as late as 1939 (Wenholz *et al.*, 1940). N.P. 12, another selection from local wheat, was found very promising in Uttar Pradesh and a sizeable area was brought under this wheat.

These early wheats were extensively used in subsequent wheat hybridization work at the Institute as also in other states of India. Thus, N.P. 4 was used as one of the parents for the production of N.P. 80-5, N.P. 100, N.P. 101, N.P. 165, N.P. 770, Niphad-4, Pb. C. 281 and others. N.P. 111 was reported to have originated as a mutation in N.P. 4, while N.P. 775 arose as a natural cross from it. N.P. 6 was one of the parents of the crosses which led to the production of N.P. 52, N.P. 54 and N.P. 80-5.

Following the famous early Pusa wheats came yet another series of successful wheats, arising from the hybridization work at the Institute. N.P. 52, evolved from N.P. 6 × Punjab 9D, was found to do very well in the states of Bengal, Bihar, eastern Uttar Pradesh and Madhya Pradesh. Until recently, this was the dominant wheat of Bihar, covering about 85 per cent of the wheat area in that State. It was used as one of the parents in the production of N.P. 120, N.P. 125, N.P. 710, N.P. 718, N.P. 758, N.P. 760, N.P. 761 at the I.A.R.I., and of Hy. 278 in Madhya Pradesh. N.P. 80-5, bred from the cross N.P. 4 × N.P. 6, did very well in the hills of the Punjab and Uttar Pradesh and was recommended for commercial cultivation in that area. N.P. 111, which arose as a fully awned mutation from N.P. 4, gave good performances in parts covered by the present Madhya Pradesh State. N.P. 114, isolated at Pusa from a natural cross of the Australian variety, Federation, became successful in Sind. It was found to be highly resistant to loose smut and has been used as one of the parents in the production of N.P. 809 at the I.A.R.I.

After the Howards left the Institute in 1924, the wheat work was continued by F. J. F. Shaw. He and his co-workers reported the production of N.P. 120 derived from the cross Federation × N.P. 52, which possessed considerable resistance to yellow rust (Shaw and Pal, 1936). N.P. 125, a sister selection of N.P. 120, gave good performances in central Uttar Pradesh and it has been, and even at present is, on the list of approved varieties in that State. Another wheat evolved at the Institute during the thirties was N.P. 165 (Plate 42), selected from N.P. 4 × Federation. It was one of the best wheats produced in the country. It is an early-maturing, rust-tolerant and loose-smut-resistant variety, and has good tillering, standing ability and grain quality. It gave excellent performances in Delhi, western U.P., the Punjab and Gujarat. N.P. 165 was subsequently used as a parent in hybridization work by B. P. Pal in the production of the well-known wheats of the 'N.P. 700 series', such as N.P. 710, N.P. 718, N.P. 720, N.P. 761, N.P. 792, N.P. 797, N.P. 798, N.P. 799; and of the 'N.P. 800 series', such as N.P. 822, N.P. 823, N.P. 824, N.P. 825, and N.P. 826 and N.P. 829. It was also one of the parents of the cross which resulted in the production of N.P. 789 and N.P. 790, which are being extensively used in Indian wheat breeding as donors of black-rust and loose-smut resistance (Plates 43-45), and of the Punjab variety C. 253.

Breeding for disease resistance: While the earlier wheats fulfilled the need of the time in respect of adaptability, yield and grain quality, a majority of them were susceptible to diseases, especially the rusts and smuts. As has been stated earlier, systematic work on the breeding for rust resistance first commenced at this Institute in 1935, when knowledge regarding the physiologic races of the Indian wheat rusts became available and techniques were developed for the creation of artificial epidemics of the rusts (Pal, 1935, 1948a; Mehta and Pal, 1940).

The first wheat-breeding substation was established at Simla and subsequently the programme was considerably augmented through the setting up of a number of other substations for this work under the Institute.

The Simla centre is engaged with the work of producing *aestivum* varieties resistant to all the three rusts for the northern hilly tract extending into the states of Himachal Pradesh, Punjab, Uttar Pradesh and West Bengal. The environmental conditions prevalent in this area necessitate the breeding of long-duration wheats capable of standing considerable snowfall in the earlier stages and completing the later part of the life-cycle in a relatively short period. The substation at Bhowali in Uttar Pradesh hills serves as an important auxillary station since at that station excellent rust infection is obtained in the field even under natural conditions. The centre at Pusa (Bihar) is located in the eastern part of the Indo-Gangetic plain, in which two or, in some places, all the three rusts are of common occurrence. The Indore centre (Madhya Pradesh), situated in the predominantly *durum* tract, aims at the evolution of rust-resistant *durum* wheats for central India. In southern India, the Nilgiri and the Palni hills have only a few thousand acres under *dicoccum* wheat, but the breeding of rust-resistant wheats for this region is important since it constitutes another focus from where the rust inoculum is carried to the wheat-growing areas in peninsular India. The substation at Wellington was established with the primary object of breeding rust-resistant *dicoccum* wheats for this area.

During the last 25 years, the author and his co-workers at this Institute, including Habibur Rahman Khan, S. Sen, G. S. Murty, S. M. Sikka, S. P. Kohli, M. V. Rao, Amir Singh, S. Kedharnath, V. K. Srinivasan, V. S. Mathur and Y. M. Upadhyaya have been engaged on an intensive programme of wheat breeding which has resulted in the production of a series of successful, rust-tolerant and rust-resistant wheat varieties belonging to the 'N.P. 700 series' and 'N.P. 800 series'. (Pal, 1948b, 1951a,b; Pal *et al.*, 1954; Murty and Deshmukh, 1951; Murty, 1956). In this important task, excellent cooperation was received by them in respect of mycological work from K. C. Mehta, R. Prasada, B. B. Mundkur, J. F. Dastur, R. S. Vasudeva, V. C. Lele and L. M. Joshi.

In the first stage of the work, considerable Indian and foreign wheat materials were critically screened with regard to rust reaction and other desirable characters and those found suitable among them were used in hybridization work. The indigenous wheat collection maintained at the Institute now totals about 2,000 cultures and the foreign wheat varieties about 4,500. The Indian wheats were critically studied (Mirchandani, 1940; Somayajulu, 1951; Sen and Somayajulu, 1956; Agarwal, 1954; Pradhanang, 1955). In the initial stage some of the rust differentials were used as donors of rust resistance, such as Democrat and Mediterranean for brown rust, and Spalding's Prolific and Carsten's V for yellow rust. For black rust, some *durum* wheats, including Kubanka and Mindum, and *dicoccum* wheats like *Khapli* were sought to be used for the improvement of the bread wheats, but in this respect some of the varieties subsequently received from Kenya, such as Kenya 48F (L.1) and Kenya E. 220 (obtained from Canada under the number C. 10854) and Thatcher from the U.S.A. proved more useful. Later, some more resistant foreign varieties were used in the hybridization programme, important among these being Kenya184.P.2.A.I.F. [Timstein C.I. 12347 (Kenya-Gular-Pilot) × K. 58-New Thatch] and Kenya Ploughman 318.0.3.B.2. for black rust; Frontiera, Bowie-Texas 3708-22, 7265-5 (Egyptian *durum*), Kenya 388 AC. 2 E. 2, I-49-89 and Tremez Molle for brown rust, and Ceres Klein, Cometa Klein and Frondoso for yellow rust. Certain of the stocks like Gabo, Gaza, Yaqui 53 (Y×E.T.) 2257-15C-1C-5C-1C, Arabian *durum* (E. 2025) and Timstein× 2086 1495A-1-31-2-1 combined resistance to both black and brown rusts while certain others such as Rio Negro, La Prevision (Supreme×Mentana) combined resistance to brown and yellow rusts. Some of the genetic stocks like Yaqui 53 (Y×E.T), 2257-15C-1C-5C-1C and (Supreme×Mentana) were also resistant to a number of races of black rust as well.

In northern India, as all the three rusts are important the problem was a complex one. Hence, the wheat-improvement work was taken up in three stages. In the first stage, when no suitable resistant stocks were available for hybridization, rust losses were sought to be minimized by introducing rust-tolerant wheats. This work (Pal, 1952, 1954b, 1956, 1957a, b) resulted in the production of wheats like N.P. 710, N.P. 718, N.P. 720, N.P. 737, N.P. 758, N.P. 760 and N.P. 761, which became very successful. Of these, N.P. 710 and N.P. 718 are still under large-scale distribution and occupy over several lakh acres of wheat area in the country. The widely adaptable N.P. 710 has been in great demand in the states of Maharashtra, Gujarat, Madhya Pradesh, central Uttar Pradesh, West Bengal and parts of Orissa while N.P. 718 has covered several lakh acres in the states of Delhi, south-eastern Punjab, Rajasthan, western Uttar Pradesh, parts of Madhya Pradesh, Maharashtra, Gujarat and Orissa. N.P. 761 proved very successful in north Bihar, especially in the sugarcane factory farms. N.P. 720 and N.P. 775 were in great demand in the *tarai* region and other parts of Uttar Pradesh despite their susceptibility to loose smut.

In the second stage of the breeding programme, attention was devoted to the production of strains possessing a high degree of resistance to the individual rusts. This work led to the evolution of wheats, such as N.P. 783 and N.P. 784 (derived from Democrat×Pb.C. 518), which are resistant to brown rust; N.P. 785 and N.P. 786 (derived from Carsten's V×Pb.C. 518) resistant to all the Indian races of yellow rust; and N.P.789 and N.P.790 (derived from Thatcher×N.P. 165) resistant to all the Indian races of black rust, excepting race 122 (Pal, 1954a). Some other selections in this series, namely, N.P. 792, N.P. 797, N.P. 798 and N.P. 799 (all derived from the cross Kenya E. 220×N.P. 165) combine in them a high degree of resistance to black rust and loose smut and a large measure of resistance to brown rust. These wheats have been released for general cultivation. N.P. 792, an early-maturing wheat, has given very good performance in Himachal Pradesh, especially in the Paonta Valley and it has also been useful as an after-paddy crop in the northern hills. N.P. 798 has given consistently good performance in the states of Bihar and West Bengal, where it is now fast replacing the earlier wheat varieties, as also in the Saurashtra area of Gujarat. N.P. 797 has given good performance in Bihar, West Bengal, Orissa and Andhra Pradesh. N.P. 799 has done very well in the Madanapalli area of Andhra Pradesh.

In the third stage attempts were made to achieve a combination of resistance to all the three rusts and loose smut. N.P. 809, which was derived from a complex cross involving Democrat (resistant to brown rust), Spalding's Prolific (resistant to yellow rust), Kenya E. 220 (resistant to black rust), N.P. 114 (resistant to loose smut) and Pb.C. 518 (good standing and yielding ability), possesses a good measure of resistance to all the three rusts and a high degree of resistance to loose smut. It has done exceedingly well over a large part of the northern hilly region extending into

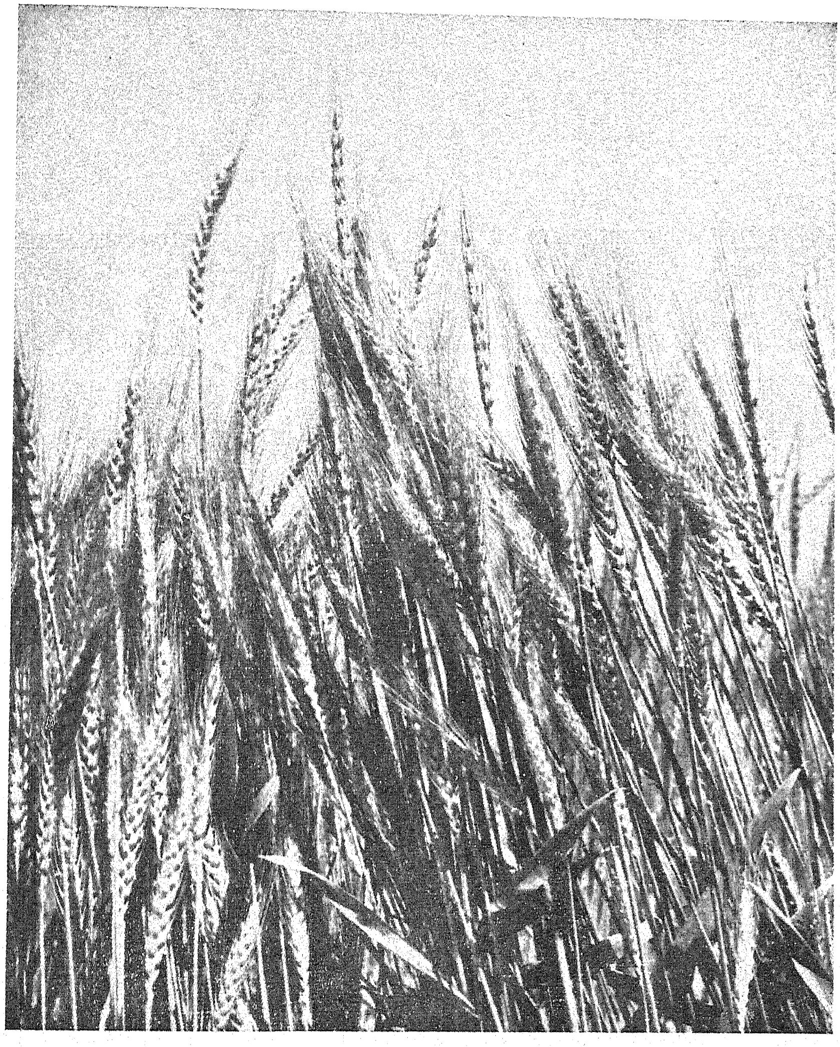


PLATE 44. N.P. 770

PLATE 45. N.P. 790, one of the most valuable sources of stem rust resistance in India.

the states of Himachal Pradesh, Punjab, Uttar Pradesh and West Bengal (Pal and Sikka, 1956a, b).

More recent wheat-breeding work at the Institute has led to the production of a series of wheats, including N.P. 822, N.P. 823, N.P. 824, N.P. 825, N.P. 826, N.P. 827, N.P. 828 and N.P. 829, some of which are highly resistant to black and yellow rusts and loose smut and have given encouraging performances in the regional trials carried out in the various states of India. N.P. 823, derived from (N.P. 165 × Pb.C. 518) × (N.P. 799 × N.P. 770), is an early-maturing wheat with excellent grain quality and has shown a high response under rainfed and irrigated conditions on soils of high as well as normal fertility and also under normal and late sowings (as late as 15th December). It has given encouraging performances in Delhi State. N.P. 824, developed from [(N.P. 165 × Pb.C. 518) × N.P. 770] × (E. 220 × N.P. 165), has given consistently good performance over a wide area both in the plains and the lower hills of northern India covering almost all the wheat-growing states of India. It is a wheat with good standing ability and responds well to heavy fertilization (Sikka and Jain, 1958a, b, 1960). A sister selection of N.P. 824, namely, N.P. 825, has been doing well in the Punjab, northern Rajasthan, Delhi and Uttar Pradesh. N.P. 829, a derivative of the cross Timstein C.I. × N.P. 165, has also given consistently high yields in the regional yield trials conducted in the lower hills (up to an elevation of 5,000 ft.) of North India. The Himachal Pradesh Department of Agriculture has already placed this wheat on its list of approved varieties.

Breeding rust-resistant wheats for the hills of North India: The work carried out at both Delhi and Simla has resulted in the evolution of superior wheats, some of which have by now covered a very large proportion of the wheat area in the northern hills. N.P. 770, evolved at New Delhi from the cross of N.P. 4 with the Japanese variety Kononso, has been released for cultivation in the higher hills. It is highly resistant to yellow rust and also to loose smut under field conditions, and possesses good standing ability and grain quality. Reference has already been made to N.P. 809, which has shown a wide adaptability in this region. Ridley, an introduction from Australia, has done exceedingly well and has good standing ability, impressive-looking ears and bold grains. It has shown a good measure of field resistance to black and yellow rusts but is susceptible to loose smut and brown rust. The encouraging performances given by N.P. 792 and N.P. 829 in these hills have already been referred to above.

Improvement of dicoccum *wheats:* At the Wellington centre, an improved strain of *dicoccum*, N.P. 200 (Plate 51), was developed by selection within indigenous material and released for general cultivation. This strain, in addition to being resistant to black and yellow rusts, is also highly resistant to brown rust under field conditions. It is superior to the local *dicoccum* in yield, grain quality and grain-to-husk ratio (Sikka and Srinivasan, 1958). The current programme of breeding work at Wellington includes the production of better-yielding and more disease-resistant (including powdery-mildew-resistant) *dicoccums*, possessing the free-threshability character for which the *dicoccum-durum* crosses are being exploited.

Improvement of durum *wheats:* Work on the improvement of *durum* wheats has been in progress at the Indore centre and aims at the evolution of mainly black-rust-resistant strains; resistance to brown rust is also receiving attention. By utilizing exotic *durums*, such as Gaza (E. 931) an Arabian *durum* (E. 2025), Egypt 8626 and another Egyptian wheat (E. 2158), in crosses with Indian *durums*, i.e., *Malvi Local*, *Ekdania 69*, *Motia*, *Gulab*, *Kathia* and *Baxi 228-18*, a series of improved strains possessing good yielding ability, high rust resistance and excellent grain quality have been bred. These strains have given very encouraging performances in preliminary tests and are ready for large-scale regional testing.

Breeding for resistance to the smuts and the bunts: In the course of development of rust-resistant *aestivum* wheats, attention has been given to the production of strains which are also resistant to the smuts (Pal and Mundkur, 1939, 1941; Mundkur and Pal, 1941; Mehta *et al.*, 1954).

With the exception of solitary examples, like N.P. 720 and N.P. 775, all the N.P. wheats of the 'N.P. 700 series' and 'N.P. 800 series' and also N.P. 114 and N.P. 165 are highly resistant to loose smut. Subsequently, loose-smut resistance has also been incorporated into N.P. 775 following a backcross programme.

The bunt diseases, also known as stinking smuts, have been receiving attention in recent years. At Simla, tests have shown that none among the Indian wheats possesses resistance to the hill bunts (*Tilletia* spp.). Some foreign wheats, such as Hussar, Brevor and White Odessa, have appeared to be highly resistant and are being extensively used in hybridization programmes.

With regard to Karnal bunt (*Neovossia indica*), experiments are underway for the development of suitable techniques for the creation of epidemic conditions necessary for screening breeding material.

Genetics of disease resistance: No programme of breeding could be complete without ancillary genetic studies. In breeding for disease resistance in wheat, especially for the rust and other pathogens which have several distinct physiologic races, the study of the mode of inheritance of resistance to individual races in the seedling stage as well as the genetics of adult plant resistance constitutes an item of basic research. Considerable research has been carried out at this Institute on the genetics of rust resistance; to this end the technique of monosomic analysis has also been exploited. The details in this regard have been presented in Chapter IV. Similar studies are underway in respect of loose smut and hill bunt.

Breeding for response to heavy fertilization: The need for developing varieties which would respond to intensive manuring and irrigation was emphasized by Pal and Parthasarathy (1948), especially in view of the country's drive towards increased food production through intensive farming practices. The breeding material has been screened in the field (Sen and Pal, 1953, 1955; Sikka and Jain, 1958b, 1960) and this has led to the production of such varieties as N.P. 823, N.P. 824, N.P. 825, N.P. 828 and N.P. 830. This line of work is now a regular feature in the wheat-breeding programme at this Institute. In recent years particular emphasis is being placed on the use of dwarf varieties which can stand up to high applications of nitrogenous fertilizers (100 lb. or more of N/acre) without lodging. Very useful material has been received from Mexico: varieties Sonora 63, Sonora 64 and Lerma Rojo are worthy of special mention. The last of these, Lerma Rojo, has given very good performance in extensive trials giving yields of about 90 md./acre (70 quintals/hectare) and has been released recently (1965) for cultivation. Because of profuse tillering the yield of straw is also good in spite of dwarf habit.

Biometrical studies on yield and its component characters: While the breeding of disease-resistant varieties is important for increasing wheat production it has been felt that investigations are required for studying directly the problem of the improvement of yield *per se*. It has been the general experience of plant breeders that certain crosses 'nick' as compared to others; hence, a plant breeder is always anxious to know as to which among the several crosses under his study would give high-yielding segregates. In hybridization work, it is relatively simple to choose the parents which would confer such obvious characters as, for instance, disease resistance. But, with regard to yielding ability it is not always true that the best-performing parental strains perform well in hybrid combinations also. In this direction biometrical studies have been carried out in several crops in foreign countries, as well as in India, and some useful methods, such as the diallel cross method, have been developed for predicting yielding ability of progenies from a series of crosses (Panse, 1940; Allard, 1956; Hayman, 1954a, b, 1958; Jinks and Hayman, 1953; Whitehouse *et al.*, 1958). Studies have also been done on the formulation of suitable selection indices which would assist in the breeding for increased yield.

Work in this direction on the wheat crop has been in progress at this Institute (Sikka and Jain, 1958a; Sikka *et al.*, 1959). It was very interesting to discover that certain varieties, such as Rio Negro, Frontiera, [(Kenya-Gular-Pilot) ×K. 58-New Thatch] and N.P. 790, were distinctly better 'combiners' as compared to others. Such information is very useful in production breeding; thus, suitable exotic and Indian varieties are regularly being tested to determine their 'combining ability'.

Breeding for special features: In addition to breeding for adaptabilty, high yield and resistance to diseases, the wheat-breeding work at the Institute also aims at the production of varieties resistant to drought and lodging. Basic physiological researches conducted at the Institute have indicated that certain indices could be utilized in a planned breeding programme for drought and lodging resistance (*see* Chapter IX). Attempts are being made to make use of this information in practical wheat breeding (Ramanujam, 1950).

Recent researches at the Institute have shown that the raising of nurseries of wheat seedlings and the subsequent transplanting of these seedlings into the field is a practical answer to the problems created by such situations as the prolonged flooding of wheat fields at the normal sowing time by late rains and river floods, as also the need for taking a wheat crop after late paddy. Varieties would, therefore, have to be developed which would give optimum performances under such conditions. Preliminary results of experiments conducted at the Institute have indicated that N.P. 710, N.P. 798 and N.P. 834 are suitable for this purpose.

Milling, baking and chapattee-*making qualities:* As mentioned earlier, the bulk of wheat consumption in India is in the form of *chapattees* and similar other preparations which are in the form of unleavened pan-cakes. However, the criteria for judging the *chapattee*-making qualities of wheat are yet rather empirical. In assessing the various wheat varieties, the principal method used has been the setting up of panels of judges, who rate the varieties on the basis of such characters as the colour of the *chapattee*, its flavour and taste, puffing ability and keeping quality. Certain physical and chemical characteristics, such as protein and gluten content, percentage of recovery of flour, ash content and sedimentation value, are also being used for the evaluation work. The establishment of the Cereal Research Laboratory at the Institute, with its modern milling, baking and cereal testing equipment, will provide a great fillip to the work on the breeding of quality wheats not only at the Institute but in the country as a whole.

Punjab. The work on the improvement of wheat crop was first undertaken at Lyallpur in the undivided Punjab in the year 1907, when a collection of local samples was made and the material classified into 25 types. One of these types, namely, Type 9, was recommended for cultivation in 1911 but was soon replaced by Type 11 in 1913. The latter variety, by 1924-25, covered an area of about half a million acres in the Punjab. A fresh collection of local samples was again made in 1914-15, and out of this a number of new strains were isolated. One of these strains was named as 8A and released for cultivation in 1919. This variety exhibited adaptability to a wide range of conditions, viz., irrigated or *barani*, rich, average and poor soils, etc. It became very popular and by 1930-31 commanded an area of about 2·5 million acres, which approximated to 25 per cent of the total area under wheat in the undivided Punjab. Certain drawbacks of this type were its late maturity and susceptibility to lodging and black rust. Another wheat developed by pure-line selection was 9D, which was released in 1930 for cultivation under *barani* conditions in all districts of East Punjab, excepting Gurdaspur and Kangra. T. Milne was in charge of the early wheat-breeding programme in the Punjab.

Until 1925, the wheat improvement work was based on pure-line selection. In order to concentrate work on cereals, a post of Cerealist was created in 1925 and Ram Dhan Singh was appointed to this post. After 1947, S. M. Sikka and L. S. Negi were associated with the wheat improvement work in the Punjab. During the middle twenties, hybridization work was taken in hand to effect further improvement in the wheat crop, and crosses were made among the Punjab types themselves as well as between improved Punjab types and certain exotic wheats. From 1940 onwards, emphasis was laid on breeding on regional basis and a number of substations (Gurgaon in 1940, Gurdaspur in 1941, Kulu in 1945 and Jullundur in 1947) were opened in important wheat-growing regions of the State. Since 1953 work on introducing disease resistance into improved Punjab wheats was taken up.

The first among the hybrid strains developed in Punjab were C. 518 and C. 591; these were released for commercial cultivation in 1933 and 1934 respectively. C. 518, which originated from the cross Type 8A×Type 9, was recommended for rich soils with plentiful supplies of irrigation and manure. It was a stiff-strawed wheat with good standing ability. C. 591, a high-yielding strain with bold, lustrous, amber, hard grains, was derived from the cross 8B×Type 9, and was one of the very successful wheats evolved by the Department. By 1952-53 it had covered about 80 per cent of the wheat area in the State. It also spread to other states, such as Uttar Pradesh, Rajasthan, Delhi and parts of Madhya Pradesh. C. 228, derived from the cross 9D× Hard Federation, was released in 1940 and recommended for cultivation in the Punjab as a late-sown crop under irrigated conditions. The grains of this wheat are very bold, attractive and are of good baking quality (Singh, 1933, 1934, 1953, 1955).

Another wheat with excellent grain quality was C. 281 (Singh and Gupta, 1959; Singh *et al.*, 1958), derived from the cross C. 591×N.P. 4. It was released for cultivation in 1955 (Negi, 1956). It is an early-maturing wheat possessing bold

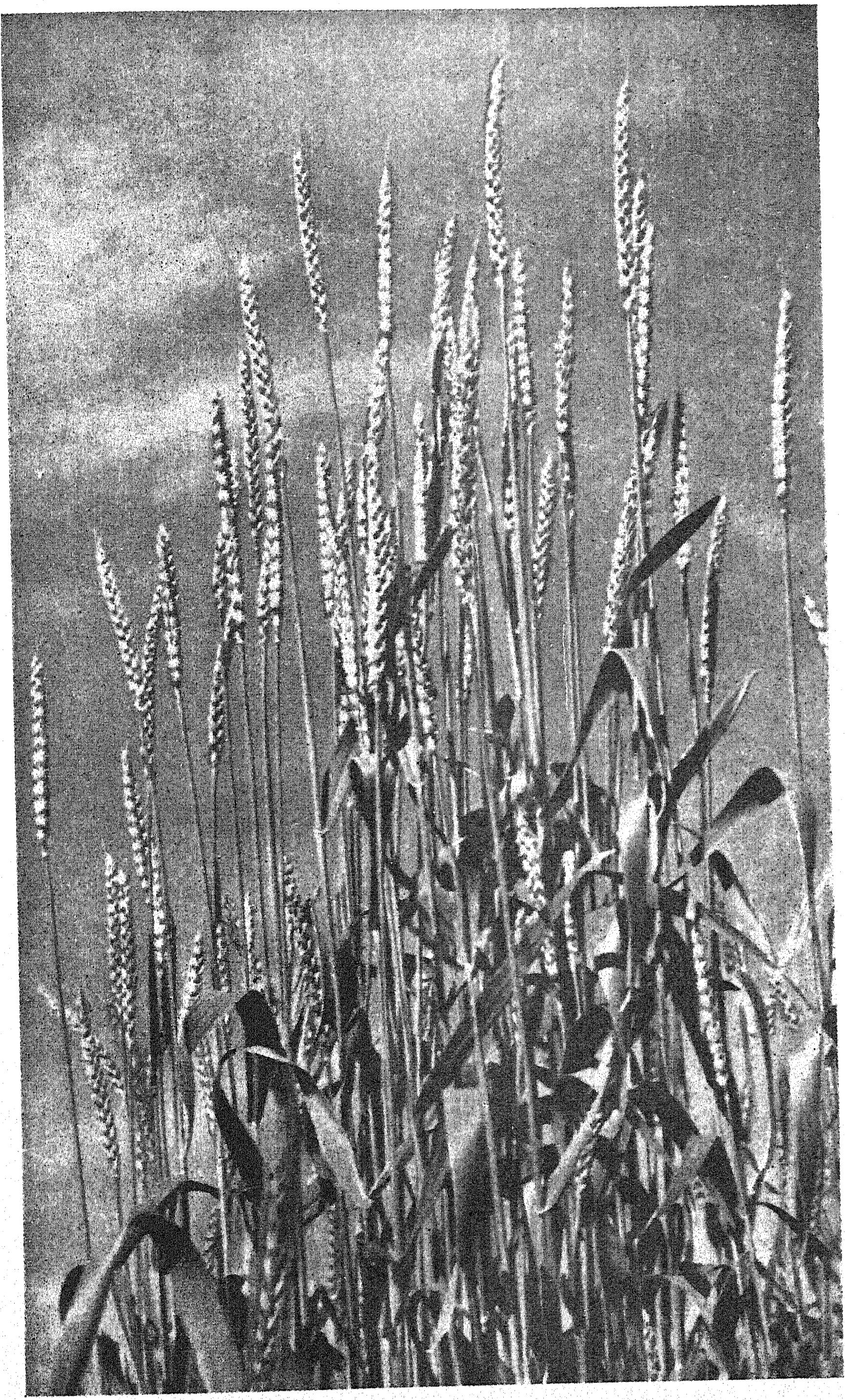


PLATE 46. N.P. 809

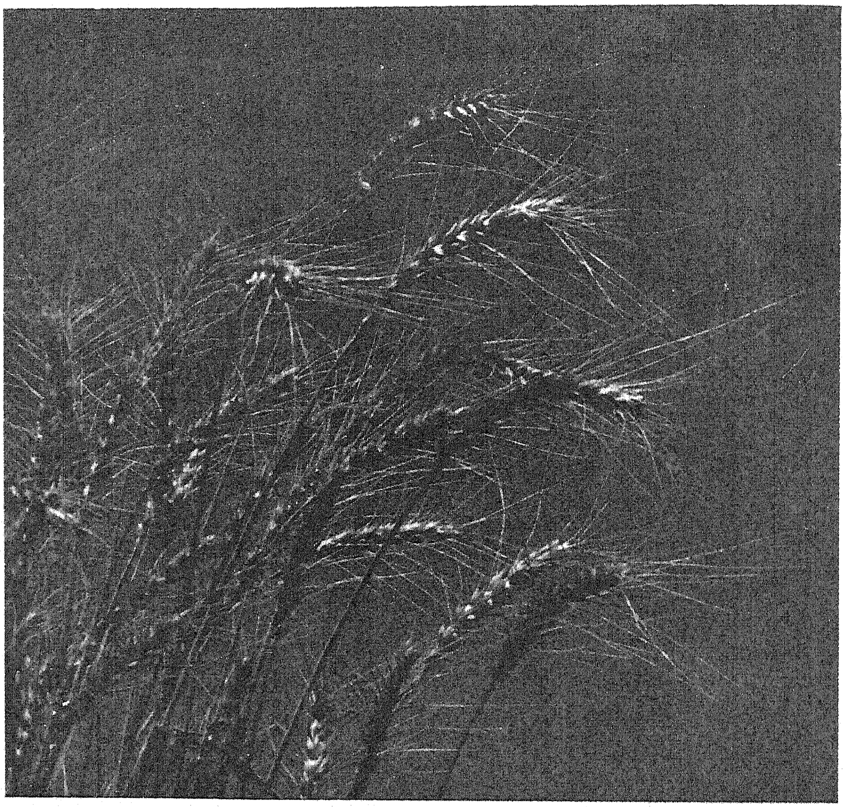


Plate 47. N.P. 823

amber seeds and does very well in the south-eastern districts of the Punjab, where hot weather sets in earlier than in the rest of the Punjab. One of the latest strains evolved in the State is C. 273, bred from the cross C. 591 × C. 209. In trials carried out on the various departmental farms it has been outyielding both C. 591 and C. 518 on soils of average and high fertility, respectively. It has attractive grains and good *chapattee*-making qualities (Negi, 1956). It may be mentioned here that all of the above-mentioned wheats are susceptible to the rusts and loose smut.

For the hills of the Punjab, five wheats have been recommended for cultivation by the Department, viz., C. 250 from the cross 9D × Hard Federation, C. 253 from the cross Type 25C × N.P. 165, C. 217 from the cross C. 228 × Kenya B 256G and C. 286 from the cross [(Type 1 × *Khapli*) × C. 591] × C. 250. The varieties C. 250, C. 253, C. 217 and C. 286 have a good measure of field resistance to yellow rust and are recommended for cultivation in the humid areas of the districts of Kangra (Sikka, 1949b) and Gurdaspur, while C. 285 is recommended for the Lahaul Valley where black rust takes a heavy toll of the local wheat crop. This wheat is fairly resistant to black rust (Negi, 1956).

The work in the Punjab (Sikka, 1949a) had so far been largely directed to production of high-yielding varieties with good grain quality. The programme of breeding for resistance to the rusts and other diseases, commenced in 1953.

Rajasthan. This is a new State which came into existence in 1949 as a result of the merger of a number of princely states. Prior to 1949, the wheat improvement work in this region primarily consisted of varietal testing. Recently, a wheat-breeding station has been set up at Durgapura, near Jaipur, under the Coordinated Wheat Rust Control Scheme sponsored by the Indian Council of Agricultural Research. Three improved varieties have been recommended for cultivation: Pb. C. 591 for the canal-irrigated areas of Sriganganagar and Bharatpur, N.P. 718 for Udaipur, Kota and parts of the Jaipur Division and R.S. 31-1 for central Rajasthan comprising Jaipur, Sawai Madhopur and parts of Jodhpur and Durgapura. R.S. 31-1 (Plate 52) is an early-maturing, fairly drought-resistant variety possessing bold, amber and hard grains. It was evolved from the cross of a local wheat with Pb.C. 591 (Bhatnagar, 1952).

Uttar Pradesh. The selection work on wheat in Uttar Pradesh began in the first decade of the present century when a number of local wheats and wheats from the adjoining states were evaluated. N.P. 4 and N.P. 12, evolved at the Indian Agricultural Research Institute (then at Pusa in Bihar), were found to give the best performances and were released for large-scale multiplication. The variety C. 13 (Plate 53) was selected at Kanpur from the local material and was released in 1916-17. During 1919-20, an awned type, was isolated from the awnless variety, C. 13; it was similar to the parent variety in all other characters, but proved superior in yield to the awnless C. 13. The awned C. 13 was taken up widely for cultivation by the farmers in central Uttar Pradesh. For the Bundelkhand area, which constitutes a distinct region of the State in respect of soil and climatic conditions, two wheat varieties, namely, K. 53 and K. 54 (Plate 54), were selected by A. K. Mitra and released for cultivation in 1951. The former was a selection from Jhansi local and the latter from the Azamgarh local. It may be mentioned here that the varieties developed by the U.P. Department of Agriculture prior to 1947 were prefixed with 'C' and those after that with the letter 'K'. In 1954, the position with regard to the wheat varieties, approved by the State Department of Agriculture, was as follows:

Eastern U.P.: N.P. 52, C. 13, N.P. 775 and N.P. 710.
Central U.P.: C. 13, N.P. 710, N.P. 720 and N.P. 125.
Western U.P.: C. 591, N.P. 720 and C. 13.
Hill areas: N.P. 4, Ridley, N.P. 770 and Padova II (an introduction from Italy).
Bundelkhand areas : *Bansi* C.P. (*durum*), K. 53 and K. 54.

In recent years, N.P. 718 has proved to be very popular in western Uttar Pradesh. Under the Coordinated Wheat Rust Control Scheme of the Indian Council of Agricultural Research a wheat-breeding centre has recently started functioning at Kanpur.

Bihar. The Indian Agricultural Research Institute was located at Pusa, Bihar, until 1936 and catered to the needs of the different wheat-growing regions of the State. N.P. 4 and N.P. 12 were among the earliest improved wheats and these were followed by N.P. 52, which covered about 80 per cent of the wheat area of the State. Subsequently, N.P. 758, N.P. 761, and currently N.P. 799 are under large-scale cultivation in north Bihar. B. R. 319, recently evolved by the Bihar Department of Agriculture, is another variety recommended for cultivation in the State (Nezamuddin and Flora, 1959). The wheat-breeding programme in Bihar is now under the immediate charge of the Cerealist, stationed at Sabour. The wheat-breeding substation of the Indian Agricultural Research Institute, located at Pusa under the Coordinated Wheat Rust Control Scheme, is actively engaged in the development of disease-resistant wheat varieties for that region.

West Bengal. The wheat area in the State extends over approximately two lakh acres; the districts of Murshidabad, Nadia, Malda, Birbhumpur and Bankura include the principal wheat-growing tracts of the State. *Gangajali* (a *durum* wheat) and N.P. 52 have been in general cultivation. In recent years, N.P. 710 and N.P. 798 have become very popular.

Under the Coordinated Wheat Rust Control Scheme, a centre has recently been started at Kalyani near Calcutta. Besides black and brown rusts, the leaf-spot diseases caused by *Helminthosporium* and *Alternaria* constitute important diseases against which resistant varieties have to be developed.

Madhya Pradesh. During the early years of the history of the State Department of Agriculture, investigations were carried out on the improvement of the wheat crop by Geoffrey Evans. He was responsible for the development of a number of selections (such as Ao. 90, Ao. 13, A. 49, A. 68, Ao. 85 and Ao. 88) and hybrid derivatives (such as A. 112, A. 113 and A. 115). Ao. 90, an amber-grained variety, originated as a selection from a Punjab wheat, called *lal kusurwala*. The white, soft-grained Ao. 13 was a selection from a local variety named *sukharai pissi.* The other soft wheats, A. 49 and A. 68 were selected from the cross, *Mundiya* (*aestivum*) × *Khapli* (*dicoccum*). A. 113 and A. 115 were derived from the cross *Mundi pissi* (*aestivum*) × *Khapli* (*dicoccum*). Of these strains, A. 115, Ao. 90 and Ao. 13 became more popular. All these wheats were susceptible to black rust and this causes considerable damage to the wheat crop in this State.

In 1941, a wheat-breeding station was set up at Powerkheda, near Hoshangabad, with financial assistance from the Indian Council of Agricultural Research. As a result of the breeding work carried out here by R. B. Ekbote, a number of black-rust-resistant hybrid strains (Hy. 5, Hy. 8, Hy. 11, Hy. 12, Hy. 25, Hy. 38, Hy. 65, Hy. 277 and Hy. 278) have been evolved. The programme of rust testing, to support the breeding work at Powerkheda, was carried out at Mahabaleshwar in Bombay State (now in Maharashtra) by V.P. Gokhale and his associates.

Among the hybrids developed at Powerkheda the most important are Hy. 65 (Plate 50), Hy. 38, Hy. 11 and Hy. 277. Hy. 11 and Hy. 38 were derived from the cross Ao. 13 × Kenya E. 220 while Hy. 65 and Hy. 277 originated from [Bobin—(Gaza ×Bobin)] × A. 115. Hy. 65 is a cosmopolitan strain which has done very well under irrigated conditions. Hy. 277 has done well in the embanked areas. Hy. 11 is another cosmopolitan strain which has done well in many parts of the State. Hy. 38, a drought-resistant strain, although inferior to the other Powerkheda hybrids with regard to rust resistance, is reported to be gaining popularity in the Narmada Valley (Ekbote and Gokhale, 1954; Ekbote and Kalamkar, 1947; Ekbote and Kaushal, 1955).

A considerable portion of the wheat area in Madhya Pradesh, especially in the Malwa region, is planted with *durum* wheats. The Institute of Plant Industry was responsible for the isolation of some high-yielding, good-quality selections from the local material, such as *Ekdania* 69 (Simlote, 1947, 1949, 1951, 1954). At the wheat-breeding substation of the Indian Agricultural Research Institute located at Indore, a good amount of work has been recently carried out on the production of some promising black-rust-resistant strains of *durum*.

Bombay. In the State of Bombay (Maharashtra and Gujarat), 90 per cent of the wheat area has been under *T. durum*, 8 per cent under *T. aestivum* and about 2 per cent under *T. dicoccum*, locally known as the *Khapli* wheat. The wheat crop in this State is mostly grown under rainfed conditions.

Prior to 1947 this State, known as the Bombay Presidency, included the territories of the present Maharashtra State (excepting the Nagpur-Berar region), parts of the present Mysore State and the present Gujarat State. With the final reorganization of the states in 1960, the districts of Gujarat, including the Saurashtra area, have been constituted into the Gujarat State; and a separate state of Maharashtra, which also included the Nagpur-Berar region and the Marathwada region of the former Hyderabad State, came into being.

The wheat-improvement work commenced in this State in the last quarter of the 19th century at Nagpur and Poona. The station at Niphad (Nasik district) has been the main wheat-breeding centre of the State since 1928. In recent years, another wheat-breeding station has been located at Badnapur in the Aurangabad district of Marathwada. All the above centres are now located in the Maharashtra State. The station at Arnej, in Ahmedabad district, was started in 1944 and is concerned with wheat-improvement work, especially for the production of varieties suited to drier conditions. This station is now in Gujarat State.

The breeding work at Niphad was further strengthened in 1943, and a programme for the development of black-rust-resistant varieties of *T. aestivum* and *T. durum* wheats was commenced with the assistance of the Indian Council of Agricultural Research.

For the pathological work, a centre was established at Mahabaleshwar in 1942, for carrying out the rust-testing work, for this and for the other wheat-breeding centres in peninsular India.

In the early stages of the work, pure-line selection was followed in the local wheat material. Among the *durums* mention may be made of *Motia* (*Bansi* 168), *Gulab* (*Bansi* 224), *Baxi* 228-18, *Arnej* 206 and *Arnej* 614, which originated by such method. Subsequently, hybridization work was taken up and two wheats, namely, *Jay* and *Vijay*, derived from *Motia* (*durum*) × *Khapli* (*dicoccum*), were released for cultivation, the former in 1934 and the latter in 1939. Though very susceptible to black rust, these wheats were very popular with the farmers, particularly in the districts of Nasik, Nagar and Poona. Because of their very early maturity, they often escaped the ravages of rust (Pugh, 1945). *Gulab*, *Arnej* 206 and *Arnej* 614 were released for cultivation in the Bhal tract of Gujarat while *Motia* was grown in West Khandesh. Recently, work on improvement of *durum* wheat was intensified in the State and a number of selections, obtained from crosses of Gaza with adapted local wheats are now undergoing district trials.

In evolving high-yielding *aestivum* wheats, considerable success has been achieved in the State. Niphad-4, derived from the cross [*Motia* (*T. durum*) × *Khapli* (*T. dicoccum*)] ×N.P. 4 (*T. aestivum*), was released for commercial cultivation in 1942 (Kadam, 1936, 1944; Kadam *et al.*, 1937; Kadam and Kulkarni, 1938a, b; Chavan, 1950; Chavan *et al.*, 1952; Gokhale *et al.*, 1950; Nazareth, 1931). Niphad-4 has attractive, amber, hard, lustrous grains with good milling and baking qualities and is very popular in the Deccan and Gujarat areas. It is tolerant to rust.

As mentioned earlier, work on breeding for rust resistance started in 1943 in Bombay State. Crosses between Niphad-4 and Kenya 48 F (L. 1) resulted in the production of Kenphad 28 and 32, and Kenphad 21 and 25 (Gokhale *et al.*, 1950; Motwani, 1953; Chavan *et al.*, 1954). These highly black-rust-resistant strains, some of which were released for general cultivation in 1951, were very popular until they were severely affected by *Alternaria* disease. Recently, some promising strains, resistant to black rust and fairly tolerant to *Alternaria* disease, have been developed; of these the more important ones are N. 179, N. 133 (both derived from the cross Kenya C. 10854×Niphad-4), N. 177 and N. 345 (both derived from *Mondya* 417-4×Hofed). Out of these N. 177 has been recommended for the irrigated tract of Deccan and Gujarat and N. 345 for the districts of Baroda (Gujarat) and Nasik (Maharashtra).

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VII

IMPORTANT WHEAT VARIETIES OF INDIA

Descriptions of Indian wheat varieties have appeared from time to time in various journals and in crop or research reports of the Departments of Agriculture in the states. At the instance of the Standing Wheat Committee of the Indian Council of Agricultural Research, the registration of wheat varieties was taken up in 1936 and Pal *et al.* (1950) described 24 wheat varieties. Later on, however, the question of such registration was not pursued. Recently it was again taken up by the I.C.A.R., and preparation of a National Register of Improved Strains of Wheat and a National Register of Wheat Genetic Stocks is under consideration.

The Food and Agriculture Organization of the United Nations has taken upon itself the publication of important information on the wheat genetic stocks available all over the world. In their series of reports entitled " World Catalogue of Genetic Stocks of Wheat ", the F.A.O. has issued tabulated descriptions of a number of wheat varieties grown in different wheat-growing countries. The participating countries have, in addition to supplying information on the wheat varieties which are maintained by them, also taken the responsibility of supplying the seed to interested persons in other countries. The Indian Agricultural Research Institute at New Delhi has been supplying tabulated descriptions of Indian wheat varieties, and descriptions of 105 wheats have so far been sent to the F.A.O. It has not been considered necessary to reproduce the descriptions of all these wheat varieties here.

IMPORTANT IMPROVED VARIETIES

A statement showing the main characters of the more important improved wheat varieties is given in Table VIII. This is followed by more detailed notes on a small number of selected varieties.

TABLE VIII. IMPROVED VARIETIES OF WHEAT IN INDIA AND THEIR MAIN CHARACTERS (Stations at which these were evolved are printed in bold type)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
		Indian Agricultural Research Institute		
N.P. 4	Selection from local *mundia*	U.P. hills, Gujarat and Deccan of Bombay State and certain tracts of South India	Alluvial loams and black cotton soils. Both irrigated and unirrigated	Beardless with felted, white glumes. Grains amber, hard. Maturity early.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
N.P. 12	Selection from local *mundia*	U.P., Madhya Pradesh and Bihar	Alluvial loams	Beardless with smooth, brown glumes. Grains white and soft to semi-hard. Maturity medium.
N.P. 52	N.P. 6×Pb.9D	Eastern U.P., Bihar, Bengal and M.P.	Alluvial clayey loams and bunded fields	Fully bearded with smooth, white glumes. Grains amber, hard. Maturity medium. Tolerant to rust.
N.P. 80-5	N.P. 4×N.P. 6	Hilly regions of the Punjab	—	Short-tipped with white, smooth glumes. Grains amber, hard. Maturity mid-early.
N.P. 101	Muzaffarnagar white × N.P. 22	U.P., M.P. and Bihar	—	Fully bearded with smooth white glumes. Grains amber and hard. Maturity very early.
N.P. 111	Mutant from N.P. 4	Madhya Pradesh	—	Short-tipped with smooth, white glumes. Grains amber, hard and of good baking quality. Maturity early.
N.P. 114	Natural cross in Federation	Sind (now in Pakistan)	Alluvial soils	Fully bearded and black-awned with felted brown glumes. Grains amber, hard. Maturity mid-late. Immune to loose smut.
N.P. 120	N.P. 52 × Federation	Sind (now in Pakistan)	Alluvial soils	Fully bearded with smooth, brown glumes. Grains amber, hard. Maturity medium. Highly resistant to stripe rust.
N.P. 125	,,	U.P.	Alluvial loams	Fully bearded with smooth, brown glumes. Grains amber and hard. Maturity medium.
N.P. 165	N.P. 4× Federation	Delhi, parts of U.P., Bhopal and Saurashtra	Alluvial loams, black and red soils. Responds well to irrigation	Beardless with smooth, white glumes. Grains amber, hard and bold. Maturity early. Tolerant to rusts and highly resistant to loose smut.
N.P. 710	N.P. 52 × N.P. 165	Central U.P., Bombay, Gujarat, M.P., West Bengal, Orissa, Andhra Pradesh	Many soils. Does well under irrigated conditions	Fully bearded with smooth, white glumes. Tendency for top-dense ears. Grains amber, hard. Tolerant to rusts and highly resistant to loose smut. Maturity mid-early.
N.P. 715	,,	North Gujarat and Saurashtra	Irrigated conditions	Like N.P. 710 but does not have top-dense ears.
N.P. 718	,,	Delhi, Rajasthan, Orissa, Madhya Bharat, Gujarat	Sandy loams and black cotton soils	Like N.P. 710. Does not have top-dense ears. Maturity early. Tolerant to rusts. Highly resistant to loose smut.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
N.P. 720	N.P. 165 × C. 518	Southern U.P., particularly the Bundelkhand area	Does well both under irrigated and unirrigated conditions	Fully bearded with black awns and felted, white glumes. Grain amber, hard. Maturity medium; straw strong.
N.P. 721	N.P. 52 × N.P. 165	Ajmer	—	Fully bearded with smooth, white glumes; grains amber and hard. Maturity mid-early.
N.P. 728	,,	Has done well in trials in the hills of Himachal Pradesh	—	Beardless with smooth, white glumes. Grains amber and hard. Medium in maturity.
N.P. 737	Chinese White × N.P. 111	Bihar and Orissa	—	Fully bearded with smooth, brown glumes. Grains amber and semi-hard. Maturity mid-early. Resistant to leaf rust. Highly resistant to loose smut.
N.P. 745	N.P. 52 × N.P. 165	Bihar and West Bengal	—	Like N.P. 710. Maturity early.
N.P. 755	,,	Bihar	—	Fully bearded with smooth, white glumes. Grains amber, hard. Maturity medium.
N.P. 758	,,	Rajasthan, M.P. and Bihar	Heavier type of soils	Like N.P. 710. Fairly resistant to lodging and tolerant to rusts. Maturity medium early.
N.P. 760	,,	Delhi, U.P., M.B. and West Bengal	Alluvial soils	Like N.P. 710.
N.P. 761	,,	Eastern U.P., Bihar and Orissa	—	Like N.P. 710. Ears slightly lax. Maturity very early. Tolerant to stripe rust and highly resistant to loose smut.
N.P. 770	Kononso × N.P. 4	Himachal Pradesh, U.P., Bengal and East Punjab hills	Does particularly well when sown a little late in the season	Fully bearded with pubescent, white glumes. Black awns. Grains amber, hard and bold. Tillers well. Maturity late. Resistant to stripe rust and highly resistant to loose smut.
N.P. 771	,,	Rajasthan and M.P.	—	Like N.P. 770. Maturity very early. Escapes rust attack.
N.P. 775	Natural cross in N.P. 4	Delhi and U.P.	Alluvial soils and *tarai* lands	Fully bearded with smooth, white glumes. Grains amber and hard. Maturity early. Ears somewhat lax. Tolerant to rust but susceptible to loose smut.
N.P. 781	Selection from mixed hybrids	U.P., Bihar and M.P.	—	Fully bearded with felted, white glumes and black awns.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
				Grains amber and hard. Maturity medium. Partially resistant to rust. Resistant to lodging.
N.P. 789	Thatcher × N.P. 165	—	—	Short-tipped with smooth, white glumes. Grains red and semi-hard. Maturity mid-early. Immune to all the races of stem rust now prevalent in India. Highly resistant to loose smut.
N.P. 790	"	—	—	Beardless with smooth, brown glumes. Grains red and hard. Maturity mid-early. Immune to all the races of stem rust now prevalent in India. Highly resistant to loose smut.
N.P. 792	Kenya C 10854 (E. 220) × N.P. 165	Hills of H.P.	Particularly suitable for sowing after late paddy	Like N.P. 797 but very early.
N.P. 797	"	M.P., Bengal, Andhra Pradesh	—	Long-tipped with smooth, brown glumes. Grains amber and hard. Maturity early. Highly resistant to stem rust and fairly resistant to brown rust. Highly resistant to loose smut.
N.P. 798	"	Bihar, Bengal and Gujarat	—	Like N.P. 797.
N.P. 799	"	"	—	Like N.P. 797.
N.P. 801	Kenya 48 F. (L.1) (E. 144) × N.P. 120	U.P. and Bengal hills	—	Fully bearded with smooth, brown glumes. Grains red, hard. Maturity late.
N.P. 802	"	—	—	Like N.P. 801. Highly resistant to stem rust.
N.P. 809	[(Democrat × C.518) F_1 × (Spalding's Prolific × N.P. 114) F_1] × E. 220	Hills of Himachal Pradesh, U.P., Punjab and Bengal	—	Long-tipped with felted, brown glumes. Grains white, semi-hard. Resistant to a number of races of the three rusts and to loose smut. Maturity medium to late.
Ridley	Introduction from Australia	—	—	Long-tipped with white, smooth glumes. Thick straw. Grains amber, bold and hard. Fairly resistant to black and brown rusts. Susceptible to loose smut.
N.P. 822	[(N.P. 165 × C 518) F_1 × (W. 245: 33-8·5-7 × N.P. 770)] F_1	—	—	Fully bearded with white, smooth glumes. Glumes tough. Grains amber, very bold and hard. Fairly resistant to black rust and highly resistant to loose smut.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
N.P. 823	(N.P. 165 × C.518) F_1 × (N.P. 799 × N.P. 770) F_1	Delhi	—	Fully bearded with smooth, white glumes. Grains amber, bold and hard. Resistant to black rust. Highly resistant to loose smut. Maturity early. Suitable for late and normal sowings, irrigated, rainfed, high-fertility and average-fertility conditions.
N.P. 824	(W. 245·44-25: 7-5 × N.P. 770) F_1 × (C. 518 × N.P. 165) F_1	Most tracts of India	—	Fully bearded with felted, white glumes. Awns black. Grains amber, bold and hard. Highly resistant to lodging. High resistance to yellow rust and moderate resistance to black rust. Highly resistant to loose smut. Bred for high-fertility conditions.
N.P. 825	(W. 245. 44-25: 7-5 × N.P. 770) F_1 × (C. 518 × N.P. 165) F_1	Under trial. Doing well in Punjab, U.P., Rajasthan, Bihar, West Bengal and Bombay	—	Fully bearded with felted, white glumes. Awns black with spreading habit. Grains amber and semi-hard. Highly resistant to lodging and also to loose smut disease. Moderately resistant to rusts.
N.P. 826	(N.P. 165 × C. 518) F_1 × (W. 245·33-8: 5-7 × N.P. 770) F_1	—	—	Fully bearded with smooth, white glumes. Awns white. Grains amber, bold and hard. Glumes tough. Ears impressive
N.P. 827	Charter × Niphad-4	—	—	Fully bearded with smooth, white glumes. Grain amber and hard. Resistant to black rust but susceptible to *Alternaria* leaf-spot disease.
N.P. 828	Niphad-4 × W. 245. 33-8: 8-10	—	—	Fully bearded with smooth, white glumes. Awns white, grains amber, medium and hard. Resistant to black rust but susceptible to *Alternaria* leaf-spot disease.
N.P. 829	Timstein × N.P. 165	Lower hills of Himachal Pradesh and U.P.	Suitable up to 5,000′ above mean sea-level	Long-tipped with smooth, white glumes. Grains hard, amber and medium. Moderately resistant to rusts and loose smut.
N.P. 830	Gabo × Niphad-4	Undergoing trials	Suitable for rich soils	Fully bearded with smooth, white glumes. Grains hard, bold and amber. Plants short, susceptible to loose smut. Moderately resistant to rusts. Susceptible to *Alternaria* leaf-spot disease.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
N.P. 200**	Selection from local *dicoccum* wheat	Nilgiri and Palni hills	—	Fully bearded with smooth, white glumes. Grains flinty, bold, red and pointed at the ends. Hard to thresh, rachis brittle. Highly resistant to brown rust in the field.
		Punjab (Lyallpur†, Jullundur, etc.)		
Pb. 8A	Selection from Local	Punjab	Irrigated loams	Fully bearded with felted, red glumes and red awns. Grains amber and hard. Maturity medium.
Pb. 9D	,,	East Punjab and some parts of central U.P.	*Barani* conditions. Sandy to clayey loams	Fully bearded with felted, white glumes. Grains amber and hard. Maturity medium.
C. 518	Punjab Type 8A × Punjab Type 9	Punjab, northern Rajasthan and western U.P.	Heavy alluvial loams. Responds well to manuring and irrigation	Fully bearded with black awns; Glumes densely felted and white. Grains amber and hard. Maturity medium. Resistant to lodging. Susceptible to rusts and loose smut.
C. 591	Punjab Type 8B × Punjab Type 9	Punjab, Rajasthan, M.B., Vindhya Pradesh and western U.P.	Light alluvial soils	Like C. 518 but the glumes are a little less hairy and the straw weaker than C. 518. Susceptible to stem and leaf rusts and to loose smut.
C. 217	C. 518 × C.516	Punjab (Ambala District)	*Barani* conditions	Maturity mid-late. Fairly tolerant to black rust.
C. 228	Punjab Type 9D × Hard Federation	Punjab	Suited for late sowings and irrigated conditions	Fully bearded with smooth, white glumes. Grains bold, amber and hard. Maturity early. Weak straw. Fairly resistant to stripe rust.
C. 250	,,	Punjab (Gurdaspur and Kangra districts)	Suited for humid and submontane areas	Fully bearded with smooth, white glumes. Grains amber and bold. Maturity medium late. Resistant to stripe rust. Straw weak.
C. 253	25C × N.P. 165	Punjab hills	Suited particularly for humid hilly tracts of Kangra	Beardless with white, smooth glumes. Grains amber, hard. Maturity medium late. Fairly resistant to stripe rust.
C. 273	C. 591 × C. 209	Likely successor to C. 591 in the plains of Punjab	Suited for soils of high fertility	Fully bearded with white hairy glumes, awns black. Grains bold, amber in colour and less liable to mottling. More resistant to lodging than C. 591. Susceptible to rusts and loose smut. Tolerant to yellow rust.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
C. 281	C. 591 × N.P.4	S.-E. Punjab and Delhi	Suited for soils of average fertility and *barani* lands. Suitable for late sowings also	Fully bearded with felted, white glumes and awns. Grains amber, bold. Maturity early. Susceptible to rusts and loose smut.
C. 285	C. 228 × B.256 G (Kenya)	Lahaul and Spiti Valley of East Punjab	For high altitudes e.g., 10,000′ and above	Fully bearded, mid long lax ears; smooth white glumes, bold amber grains. Slightly earlier than C. 591. Highly resistant to black rust.
C. 286	[(Type 1 × *Khapli*) × C. 591] × C. 250	Punjab (Kangra and Gurdaspur districts)	Submontane areas and low hills. Suited for late sowings	Fully bearded with white, smooth glumes. Excellent grain; straw weak. Resistant to yellow rust and fairly resistant to black rust.
		Bombay	**(Niphad)**	
Bansi 202*	Selection from local *durum Bansi*	—	—	Fully bearded with felted, white glumes. Grains amber, hard and bold. Maturity early.
*Motia** (*Bansi* 168)	,,	West Khandesh in Bombay State	Deep black cotton soils. Dry areas	Fully bearded with smooth, brown glumes and light yellowish grains. Maturity early.
*Gulab** (*Bansi* 224)	,,	East Khandesh and *bhal* tract of Gujarat	Yields well on heavy soils	Like *Motia*. Grains slightly pinkish yellow. Maturity mid-early.
*Jay** (*Bansipalli* 808)	*Motia* × *Khapli*	Bombay, Karnatak and Deccan	Deep black cotton soils	Fully bearded with smooth, white glumes. Grains whitish-yellow, semi-hard. Maturity very early.
*Vijay** (Niphad-81)	*Motia* × *Khapli* (natural cross)	,,	,,	Like *Jay*. Grains yellowish.
Niphad-4	(*Motia* × *Khapli*) × N.P. 4	Throughout Bombay State	Responds very well to irrigation and manuring	Fully bearded with black awns; glumes felted and white, slightly hard threshing; grains whitish-yellow and semi-hard. Very good milling and baking quality.
Kenphad (yellow early) No. 28	E. 144 [Kenya 48.F (L.1)] × Niphad-4	Deccan and Gujarat	Suitable for *barani* conditions but responds well to irrigation. Medium to heavy black soils	Fully bearded with black awns. Glumes felted and brown. Grains hard, amber and lustrous. Resistant to black rust.
Kenphad (yellow early) No. 32	,,	,,	,,	Fully bearded with black awns. Glumes felted and white. Grains soft. Resistant to black rust.
Kenphad (yellow mid-late) No. 25	,,	,,	Suitable for *barani* conditions but responds well to irrigation. Medium to heavy black soils	Like Kenphad (yellow early) No. 28. Maturity mid-late. Resistant to black rust.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
Kenphad (red mid-late) No. 39	E. 144 [Kenya 48.F. (L. 1)] × Niphad-4	Bombay and Karnatak	Suitable for *barani* conditions but responds well to irrigation. Medium to heavy black soils	Fully bearded with smooth, white glumes. Grains red and lustrous. Resistant to black rust.
N.179	Kenya C. 10854 × Niphad-4	Kaira, Mehsana, Ahmedabad and Banaskantha districts	—	Fully bearded with felted, white glumes. Awn black. Grains hard, bold and amber.
N. 133	,,	Amreli and Mehsana districts	—	Fully bearded with felted, brown glumes. Awns black. Grains hard, bold and amber.
N. 177	*Mondva* 417-5 × Hofed	Amreli, Kaira, Banaskantha, Broach, Sabarkantha, Ahmednagar and Ahmedabad districts	—	Fully bearded with felted, white glumes. Awns black. Resistant to black rust. Grains hard, amber and bold.
N. 345	,,	,,	—	Fully bearded with felted, brown glumes. Awns black. Resistant to black rust.
		Bombay (Arnej)		
Arnej 206*	Selection from local wheat of Gujarat	*Bhal* tract of Gujarat	—	Fully bearded with smooth, white glumes. Grains amber, hard and bold. Susceptible to rusts.
Arnej 624*	Selection from local *Raiha katta*	,,	—	Same as Arnej 206 but glume colour brown.
		Bombay (Badnapur, formerly in Hyderabad)		
P.W. 5	Selection from *Potia* wheat from Aurangabad District	Marathwada and Karnatak	Heavy soils	Fully bearded with smooth white glumes. Grains white and soft. Susceptible to rusts.
P.W. 12	,,	Nizamsagar Project area of A.P.	—	Like P. W. 5.
P.W. 3*	Selection from *Bansi* wheat from Osmanabad District	Marathwada and Karnatak	Medium heavy soils	Fully bearded with smooth, white glumes. Awns spreading. Grains bold, hard and amber. Susceptible to rusts.
		U. P. (Kanpur)		
K. 13 (C. 13)	Selection from local wheat	Central U.P.	Irrigated, alluvial loams	Fully bearded with smooth, white glumes. Grains amber and semi-hard. Maturity early. Susceptible to rusts and loose smut.
K. 46 (C. 46)	Selection from K. 13	Southern U.P.	*Barani* tracts	Like K. 13. But grains are shorter than those of K. 13.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
K. 54 (C. 54)	Selection from *Desi* local of Azamgarh	Bundelkhand area of U.P.	—	Fully bearded, glumes smooth and white, ears long and lax. Grains medium, semi-hard and red. Fairly resistant to black and yellow rusts.
Padova I	Introduction from Italy	Hills of U.P.	—	Fully bearded with smooth, brown glumes. Grains amber, semi-hard and medium late in maturity.
Padova II	,,	,,	—	Like Padova I but ears shorter and glumes darker brown.
Madhya Pradesh (Akola and Powerkheda)				
Ao. 13	Selection from *Sukharai Pissi*	M.P. (Hoshangabad District)	*Barani*. Not suited to wet lands	Fully bearded with white, glabrous glumes. White, soft grains. Maturity early. Drought tolerant.
Ao. 85	,,	,,	,,	Like Ao. 13, but earlier in maturity.
Ao. 88	Selection from *Muria*	Jabbalpur	,,	Ears long-tipped with smooth, white glumes. Grains white and soft.
Ao. 90	Selection from *Lal Kusurwala*	Jabbalpur and Narsinghpur districts	For irrigated light soils and embanked areas	Fully bearded with smooth, dark-brown glumes. Grains white and soft. Maturity late.
Ao. 68	Local *Mundya* (*T. aestivum*) × *Khapli* (*T. dicoccum*)	,,	Irrigated lands	Fully bearded with smooth, white glumes. Grains amber and semi-hard. Maturity early.
A. 113	*Mundi Pissi* (*T. aestivum*) × *Khapli* (*T. dicoccum*)	Northern districts of M.P.	Both irrigated and non-irrigated conditions	Like Ao. 68.
A. 115	,,	Northern districts of M. P.	Both irrigated and non-irrigated conditions	Like Ao. 68, but with stiff straw and dense ears.
Hy. 278	N.P. 52 × Ex. 30	M.P.	—	Ear mid-dense, fully bearded. Glumes white and smooth. Grains amber and medium hard. Maturity very late. Resistant to black rust.
Hy. 11	A. 115 × Kenya E. 220	M.P. (Narmada Valley)	—	Ear dense and fully bearded. Glumes white and smooth. Grains, white and soft. Ear with branching tendency when grown under irrigation. Maturity mid-late. Resistant to black rust.

TABLE VIII (*Contd.*)

Variety	Pedigree	Suitability to		Main characters
		Region	Conditions	
Hy. 12	As for Hy. 11	M.P.	—	Like Hy. 11, but less resistant to black rust. Ears lax with spreading awns.
Hy. 38	Ao. 13×Kenya E. 220	M.P. (Narmada Valley)	—	Fully bearded with smooth, white glumes. Grains white. Maturity medium. Tillering good. Somewhat drought resistant.
Hy. 277	[Bobin × (Bobin-Gaza)] × A.115	M.P.	Embanked areas	Fully bearded with smooth, white glumes. Grains amber and semi-hard. Maturity late.
Hy. 65	[Bobin × (Bobin-Gaza)] × A. 115	M.P.	Both under irrigated and unirrigated conditions but responds well to irrigation	Like Hy. 277, but maturity medium. Ears impressive and grains attractive, amber, bold, hard and lustrous. Resistant to black rust.
Hy. 5	Ao. 90×Kenya E. 220	—	—	Fully bearded with smooth, brown glumes. Grains amber and semi-hard. Has got grain-shattering tendency. Tolerant to rusts.
Ekdania 69*	Selection from Malvi *durum*	Former Madhya Bharat and south-eastern Rajasthan	Black cotton soils and rainfed condition	Fully bearded with white smooth glumes. Grains amber, bold, hard, lustrous, uniform and very attractive. Susceptible to rusts.
		Rajasthan	**(Durgapura)**	
R.S. 31-1	Pb. C. 591 × Local	Rajasthan	Soils of average fertility and *barani* lands	Fully bearded with white, smooth glumes, ears compact, grains amber, hard, bold. Very early in maturity. Susceptible to rusts. Escapes from black rust due to early maturity.
		Bihar	**(Sabour)**	
B.R. 319	Selection from local wheat	Bihar	—	Awnless wheat with smooth, white glumes. Grains amber, hard, medium bold. Susceptible to rusts. Looks almost like N.P. 165. Maturity early.

Note : Most of the strains belong to the species *Triticum aestivum*. Strains belonging to *T. durum* and *T. dicoccum* have been indicated by single and double asterisks respectively.

† Lyallpur is now in Pakistan.

DESCRIPTION OF SELECTED IMPROVED VARIETIES

N.P. 4

N.P. 4 (Plates 40, 55) originated as a selection from local *mundia* at the Imperial (now Indian) Agricultural Research Institute. It was distributed for general cultivation in the first decade of this century.

N.P. 4 is beardless, with pubescent, white and persistent glumes. The grains are of high quality, hard, amber-coloured, plump and medium in size. The protein content is about 9·69 per cent.

It is an early-maturing variety with fairly good standing ability. It is susceptible to the rusts and loose smut. In rust-free years, an average yield of 16 md. per acre and a highest yield of 40 md. per acre have been reported. This was an important variety once in the hills of Uttar Pradesh, in Gujarat and in the Deccan tracts of Bombay State. Now other improved varieties have replaced this. During the period 1916-1920 this variety got the first prize four times in international grain exhibitions.

N.P. 52

N.P. 52 (Plate 55) is a selection from a cross between Pusa 6 and Punjab 9D. This variety was evolved at the Indian Agricultural Research Institute by the Howards and was released for commercial cultivation in the early twenties.

The ears are fully bearded, compact and mid-long with glabrous, white glumes. The grains are hard, medium and amber-coloured with a protein content of about 9·06 per cent.

It is of mid-early maturity and was once a very popular wheat in Bihar, U.P., Bengal and in some areas of Madhya Pradesh and Bombay.

N.P. 52 is tolerant to black rust and highly susceptible to loose smut and yellow rust. The average yield recorded is 18 md. per acre and the highest 33 md. per acre. The variety is moderately resistant to drought.

N.P. 125

N.P. 125 (Plate 55) was developed by the Howards at the Indian Agricultural Research Institute from the cross N.P. 52 × Australian Federation. It was released for commercial cultivation in the first quarter of this century.

It is a fully bearded, early-maturing wheat with smooth, brown glumes. Ears are compact with a tendency for clubbing at the top. Grains amber to white, medium and hard. The variety is a heavy yielder with an average yield of 20 md. per acre and a highest recorded yield of 63 md. per acre.

The variety is recommended for commercial cultivation in central U.P.

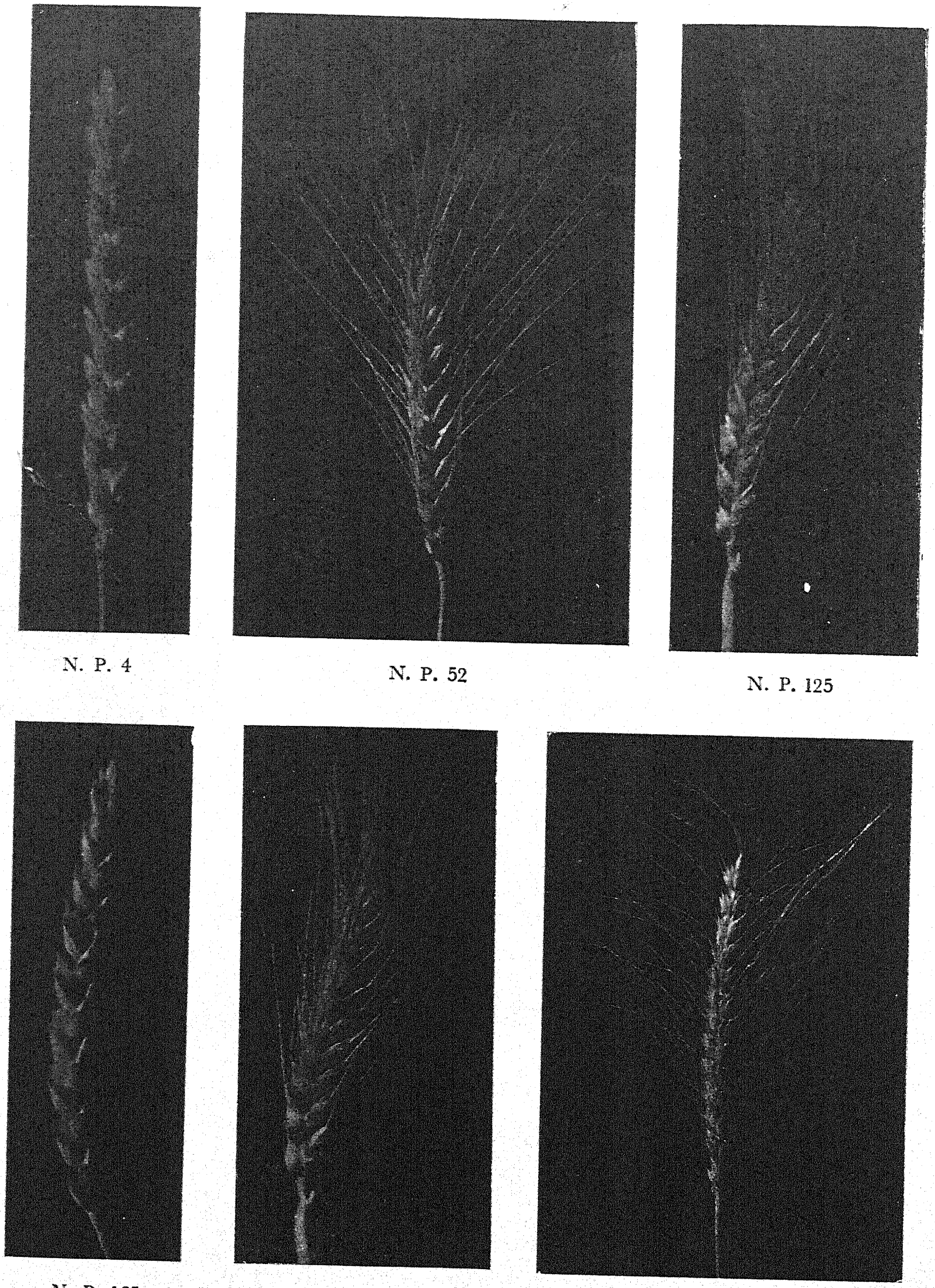
N.P. 125 is susceptible to rusts and loose smut. When sown early, it escapes from black rust.

N.P. 165

N.P. 165 (Plates 42, 55) is a selection from a cross of N.P. 4 and Australian Federation, developed at the Indian Agricultural Research Institute. It was released for commercial cultivation in the late thirties.

It is a beardless, early-maturing wheat with white, smooth glumes. Straw is medium tall with good standing ability. It has hard, amber-coloured, bold grains with a protein content of 12·46 per cent. It is a high yielder with an average yield of 20 md. per acre and a highest recorded yield of 40 md. per acre.

This was once the recommended variety for Delhi, certain tracts of U.P., Saurashtra and Bhopal.



N. P. 4

N. P. 52

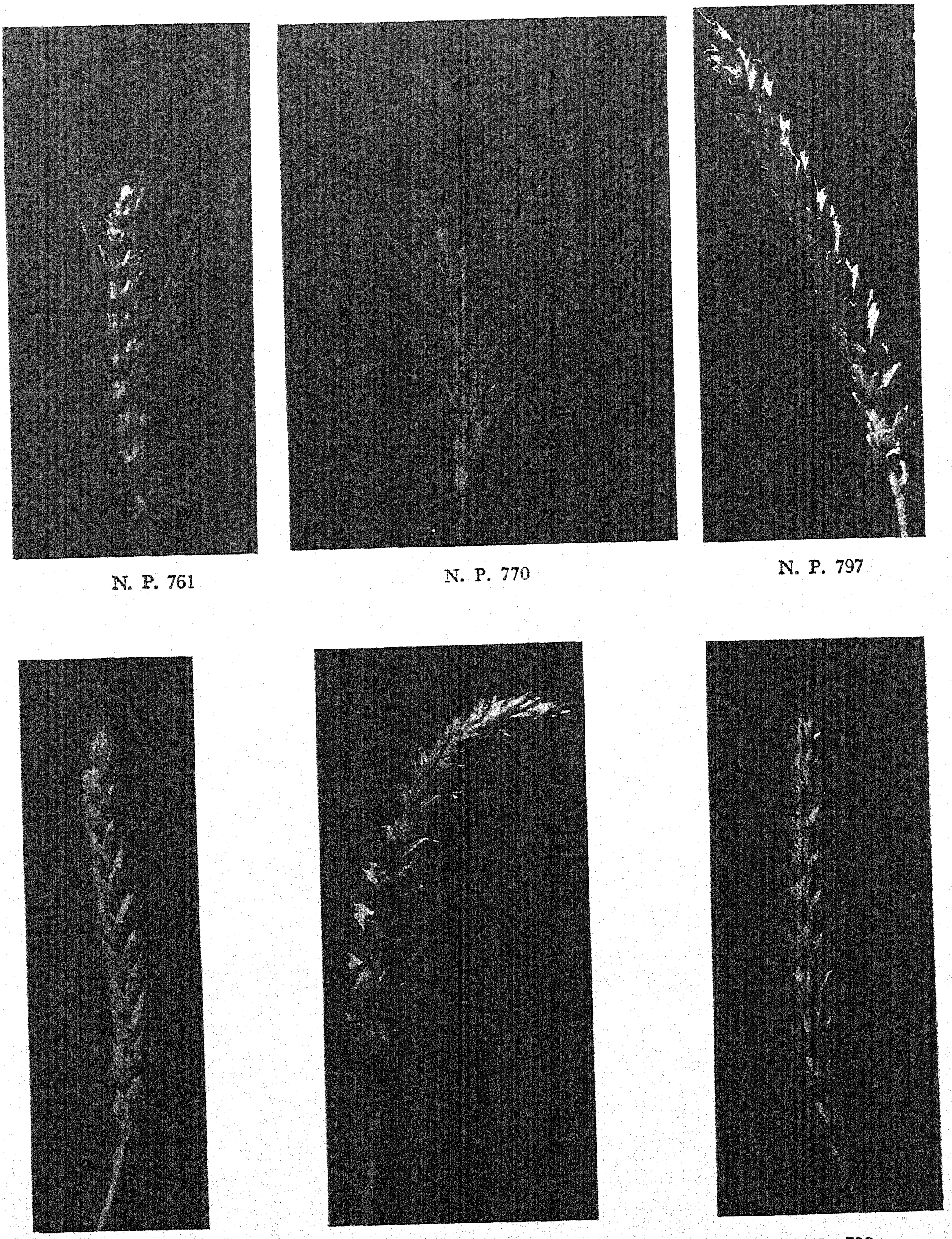
N. P. 125

N. P. 165

N. P. 710

N. P. 718

PLATE 55. Ears of N.P. 4, N.P. 52, N.P. 125, N.P. 165, N.P. 710 and N.P. 718



N. P. 761

N. P. 770

N. P. 797

N. P. 792

N. P. 798

N. P. 799

Plate 56. Ears of N.P. 761, N.P. 770, N.P. 797, N.P. 792, N.P. 798 and N.P. 799

It is tolerant to and because of its earliness it often escapes the ravages of black rust. The variety shows moderate field resistance to yellow rust and high resistance to loose smut.

N.P. 710

N.P. 710 (Plates 43, 55) is a selection from a cross between N.P. 52 and N.P. 165, developed at the Indian Agricultural Research Institute by Pal, and was released for commercial cultivation in 1948.

N.P. 710 is a fully bearded wheat, with mid-long dense ears and white smooth glumes. The grains are hard, amber-coloured, medium to bold in size. The protein content is about 12 per cent.

The variety has good standing ability. The plant is of medium height and the tillering is moderate. It yields well under a variety of climatic and soil conditions. It is thus more cosmopolitan than any other N.P. variety so far produced. This variety has fared well in all the states from Bengal to Bombay, U.P. and Delhi. An average yield of 21 md. per acre and a highest recorded yield of 40 md. per acre has been obtained with this wheat.

This variety is highly resistant to loose smut and is tolerant to the rusts.

This wheat is widely cultivated and is recommended for commercial cultivation in the states of Madhya Pradesh, Bombay, Uttar Pradesh, West Bengal, Orissa, Gujarat and to some extent in Andhra Pradesh.

N.P. 718

N.P. 718 (Plate 55) was developed by Pal from the cross N.P. 52×N.P. 165 at the Indian Agricultural Research Institute. It was released for general cultivation in 1948.

N.P. 718 is a fully bearded wheat with white, glabrous glumes. The plant grows to medium height and tillers well. It is a heavy yielder. Average yield of 20 md. per acre and a highest recorded yield of 45 md. per acre have been reported. It is a very early-maturing variety, fairly resistant in the field to yellow and black rusts, susceptible to brown rust and very highly resistant to loose smut.

The grains are hard, medium-sized, lustrous and of good quality. The protein content is about 11·2 per cent.

The variety is commercially cultivated in the states of Uttar Pradesh (western), Madhya Pradesh, Bombay, Orissa, south-east Punjab and Rajasthan. It also does well in Bihar and Gujarat.

N.P. 761

N.P. 761 (Plate 56) originated as a selection from the cross N.P. 52×N.P. 165 attempted by Pal at the Indian Agricultural Research Institute.

It is a fully bearded wheat with white awns. The glumes are white and smooth. The grains are hard, medium to small and amber-coloured with a protein content of 10·03 per cent. Maturity very early.

On account of its earliness it practically escapes the ravages of black rust. It is fairly resistant to loose smut and yellow rust under field conditions.

This variety has been found to do well in north Bihar, Orissa and eastern U.P.

N.P. 770

N.P. 770 (Plate 56) was developed by Pal from the cross Kononso × N.P. 4 at the Indian Agricultural Research Institute. It is a late-maturing variety suitable for growing at higher elevations in the hills of North India. This variety has been brought under the list of approved varieties recommended for cultivation by the Himachal Pradesh Department of Agriculture. It is a handsome-looking, tall-growing variety with good standing ability.

N.P. 770 is fully bearded with black awns and felted, white glumes. The ears are long and very attractive. The grains are bold, hard and amber-coloured, with a protein content of 10·15 per cent. Average yields of 27 md. per acre and a highest yield of 57 md. per acre have been reported so far for this variety.

It is highly resistant to loose smut and yellow rust under field conditions and susceptible to black and brown rusts. This wheat is recommended for cultivation in the higher hills (above 5,000 ft.) of Himachal Pradesh, U.P., Punjab and West Bengal.

N. P. 792

N.P. 792 (Plate 56) is a selection derived from the cross Kenya C 10854 (E. 220) × N.P. 165 at the Indian Agricultural Research Institute.

The variety is long-tipped with glabrous, brown glumes and amber, medium-sized, semi-hard grains. Plants are medium tall. Maturity very early. The protein content is 9·37 per cent.

N.P. 792 is highly resistant to black rust and loose smut and moderately susceptible to brown and yellow rusts.

The variety has established itself in Paonta Valley of Himachal Pradesh. The variety has also been taken up in the hills of Himachal Pradesh and Uttar Pradesh for getting a crop of wheat after late paddy.

N.P. 797

N.P. 797 (Plate 56) originated as a selection from the cross between Kenya C. 10854 (E. 220) and N.P. 165 at the Indian Agricultural Research Institute.

N.P. 797 has fusiform, long, mid-dense ears, which are long-tipped. The glumes are light brown in colour and smooth. The grains are semi-hard, medium-sized and amber-coloured. The protein content is 9·38 per cent. Maturity early.

It is highly resistant to stem rust and loose smut and fairly resistant to brown rust.

This variety has been doing well in Andhra Pradesh, Orissa, Bihar and Bengal.

N.P. 798

N.P. 798 (Plate 56) is a selection evolved at the Indian Agricultural Research Institute from the cross Kenya C 10854 (E. 220) × N.P. 165.

The ears of this variety are long-tipped, fusiform and mid-dense. The glumes are light brown in colour and smooth. The grains are semi-hard and amber-coloured. The protein content is 9·44 per cent. Maturity is early. The variety looks very much like N.P. 797. This variety has given consistently good performance in Bihar and is fast replacing N.P. 761 and other earlier wheats.

It is highly resistant to stem rust and loose smut, and fairly resistant to brown rust. The variety gave very good yields during the black-rust epidemic of 1956 in Bihar, as compared to the local wheats.

N.P. 798 is recommended for commercial cultivation in the states of Bihar, West Bengal and Gujarat.

N.P. 799

N.P. 799 (Plate 56) is a sister selection of N.P. 797 and N.P. 798, derived from the cross between Kenya C. 10854 (E. 220) and N.P. 165 at the Indian Agricultural Research Institute.

N.P. 799 has fusiform long ears, which are long-tipped. The glumes are light brown in colour and smooth. The grains are semi-hard and amber-coloured. The protein content is 10·77 per cent.

This variety has been reported to be giving good performance in Andhra Pradesh.

N.P. 799 is highly resistant to loose smut and to stem rust and fairly resistant to brown rust.

N.P. 809

N.P. 809 (Plate 57) is a selection from a complex cross involving the varieties Democrat, C. 518, Spalding's Prolific, N.P. 114 and Kenya E. 220. It was developed at the Indian Agricultural Research Institute and is the fruit of a planned effort to combine in one variety resistance to as many races of the three wheat rusts as possible.

N.P. 809 is a tall-growing wheat with long attractive ears. The ears are long-tipped with felted, brown glumes. The grains are white and semi-hard. The protein content is 10·97 per cent. The plants are attractive to look at when in ear. Maturity medium to late. It is resistant to a number of races of the three rusts and to loose smut.

It is recommended for general cultivation in the medium elevation hills of Himachal Pradesh, Uttar Pradesh, East Punjab and West Bengal.

N.P. 823

N.P. 823 (Plate 57) originated as a selection from the cross (N.P. 165 × C. 518) F_1 × (N.P. 799 × N.P. 770)F_1 made at the Indian Agricultural Research Institute.

It has very impressive ears, which are fully bearded with smooth white glumes. The grains are bold, amber-coloured and hard. Maturity early. The protein content is 11·97 per cent.

N.P. 823 is fairly resistant to black rust and yellow rust and highly resistant to loose smut. It is susceptible to brown rust. The variety shatters if not harvested in time.

The variety was found to be a general-purpose wheat suitable for cultivation under a wide range of conditions such as normal and late sowings, irrigated and rainfed crops and for soils of average as well as of high fertility.

The variety is finding favour with the farmers round about Delhi.

N.P. 824

N.P. 824 (Plate 57) was developed from the cross [W. 245(44-25 : 7-5)×N.P. 770]F_1× [C. 518×N.P. 165]F_1 at the Indian Agricultural Research Institute.

It is a medium-duration wheat with very attractive bold ears. The ears are fully bearded with felted, white glumes. The awns are black. The grains are medium, hard and amber-coloured. The protein content is 11·57 per cent.

The variety shows considerable field resistance to yellow rust and moderate resistance to black rust. It is also highly resistant to loose smut and to lodging. It is a heavy yielder particularly under high-fertility conditions and under normal sowings.

The variety is widely adapted and is reported to be doing well in U.P., West Bengal, Bihar, Madhya Pradesh, Bombay, Orissa and Mysore. It has also done very well in the lower elevations of North India from Kashmir to Kalimpong.

N.P. 829

N.P. 829 (Plate 57) has been developed at the Indian Agricultural Research Institute from the cross Timstein×N.P. 165. The variety was released for general cultivation in the hills of North India during 1958-59.

N.P. 829 is a tip-awned wheat with glabrous white glumes. Grains amber, hard and medium-sized. Plants medium tall. Maturity medium late.

The variety is moderately resistant to all the three rusts and loose smut in the field. N.P. 829 is recommended for general cultivation in the lower hills (up to 5,000 ft. above mean sea-level) of Himachal Pradesh and U.P., where it was found to outyield the earlier recommended wheat, Ridley.

N.P. 200

N.P. 200 (Plate 57) originated as a selection from the local *samba* wheat (*Triticum dicoccum*) of Rishi Valley, Andhra Pradesh. The strain was released by the Indian Agricultural Research Institute for general cultivation during 1958-59.

This wheat is fully bearded with glabrous white glumes. Glumes tough and rachis brittle. Grains flinty, bold and red. Height medium. The protein content is 15·05 per cent. N.P. 200 is moderately resistant to black rust and highly resistant to brown rust in the field. The variety is also superior to the local *dicoccum* wheat in its high grain-to-husk ratio and grain quality.

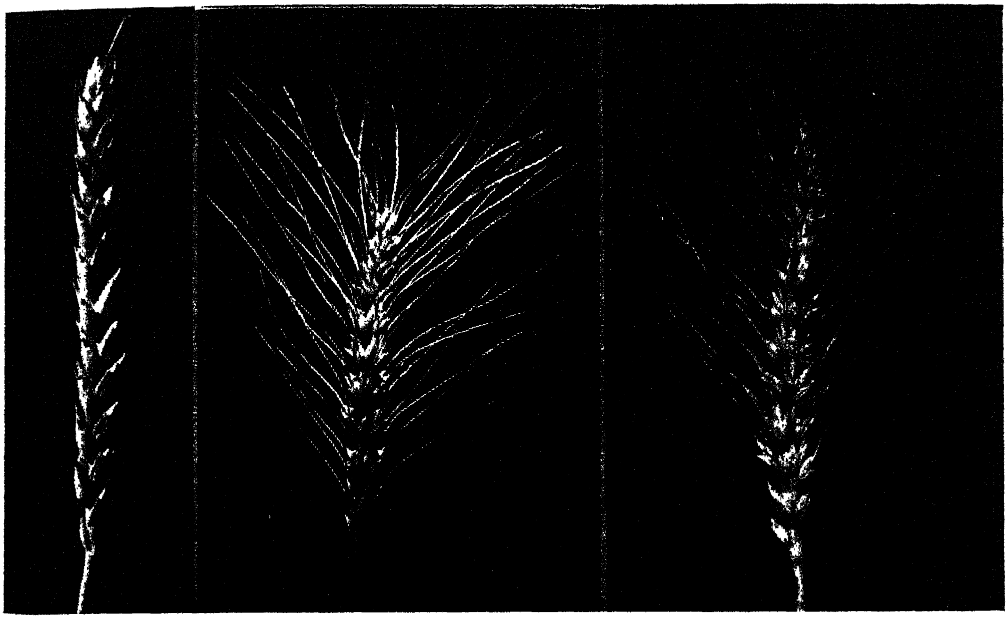
It is recommended for general cultivation in the Nilgiri and Palni hills and other adjoining areas of South India.

Ridley

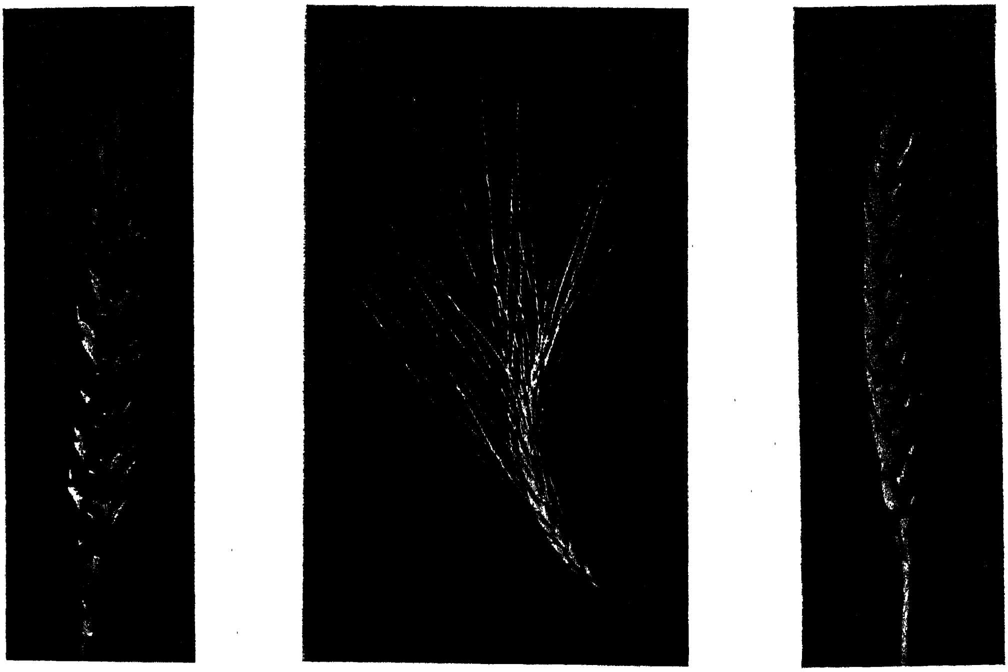
Ridley (Plate 57), obtained from the cross (Nabawa×Hard Federation) × Gabo, is an introduction from Australia.

The variety was released in hills of North India by the Indian Agricultural Research Institute. Ridley is a medium-tall wheat with thick straw. The ears are long-tipped, bold, compact and impressive. Glumes white and smooth. Grains bold, amber and semi-hard.

Ridley is fairly resistant to black and yellow rusts. It is susceptible to loose smut and brown rust. The variety is fairly resistant to lodging.

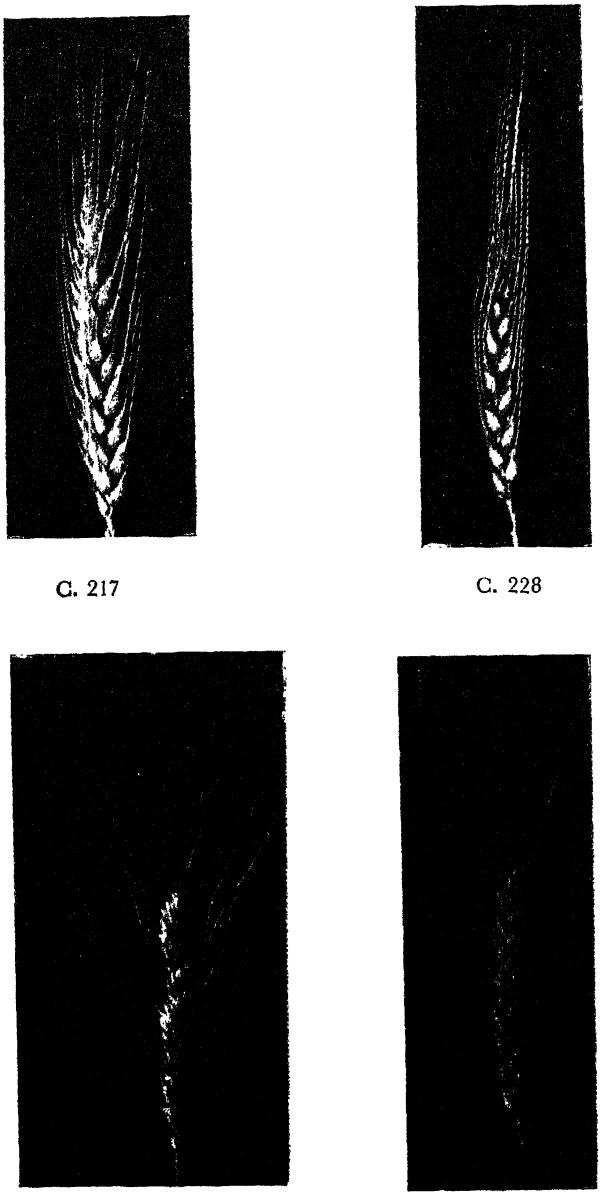


N. P. 809 N. P. 823 N. P. 824



N. P. 829 N. P. 200 Ridley

PLATE 57. Ears of N.P. 809, N.P. 823, N.P. 824, N.P. 829, N.P. 200 and Ridley



C. 217 C. 228

C. 591 C. 518

Plate 58. Ears of C. 217, C. 228, C. 591 and C. 518

Ridley has been extensively adopted for cultivation in the lower altitudes in the hills of Himachal Pradesh, U.P. and the Punjab. An average yield of 20 md. per acre and a highest yield of 45 md. per acre have been reported. The variety does particularly well if the cold season is prolonged for some time.

C. 591

C. 591 (Plate 58) originated as a selection from the cross Punjab Type 8B × Punjab Type 9, and was evolved by the Punjab Department of Agriculture. It was first released for distribution in the year 1934. It is the most popular wheat of the Punjab.

C. 591 is a fully bearded wheat with black awns and white, felted glumes. The grains are hard, medium-sized, amber-coloured and very attractive, with excellent *chapattee*-making qualities. The protein content is 10·9 per cent. It is medium in maturity and is primarily recommended for normal sowing.

It withstands lodging fairly and as such does very well under high soil-fertility conditions also. C. 591 is susceptible to all the three rusts and loose smut.

The variety commands about 80 per cent of the total area under wheat in the Punjab. It is also grown extensively in U.P., northern Rajasthan and Madhya Pradesh.

C. 518

C. 518 (Plate 58) is a strain developed by the Punjab Department of Agriculture from the cross Punjab Type 8A × Punjab Type 9 and released for commercial cultivation during 1933-34.

C. 518 has short, dense ears, which are fully bearded with black awns. The glumes are white and densely felted. The grains are hard and amber-coloured with a tendency towards mottling. The straw is short and thick and withstands lodging well under rich soil conditions. It is one of the high-yielding Indian wheats and yields up to 58 md. per acre have been reported. The 1951-52 wheat *Krishi Pandit* in the Ludhiana district of the Punjab obtained the highest yield of 71·58 md. per acre with this variety.

The variety is of medium late maturity. It is very susceptible to rusts and loose smut. Recommended for rich soils in the Punjab, northern Rajasthan and western U.P.

C. 286

C. 286 (Plate 59) resulted as a selection from the complex cross [(Type 1 × *Khapli*) × C. 591] × C. 250, and was developed by the Punjab Department of Agriculture. This is one of the recently evolved varieties of wheat in the Punjab.

C. 286 is fully bearded with smooth, white glumes. The awns are white. The ears are mid-lax. The grains are bold, hard and amber-coloured. It possesses very good *chapattee*-making qualities.

It is highly resistant to yellow rust and has also a fair degree of resistance to stem rust. The straw is weak and is, therefore, liable to lodge on rich soils. This variety is recommended for cultivation in humid areas like Gurdaspur and Kangra districts of the Punjab.

C. 285

C. 285 (Plate 59) originated as a selection from the cross C. 228 × B. 256G and was developed by the Punjab Department of Agriculture. B. 256G is a stem-rust-resistant wheat from Kenya.

C. 285 is a fully bearded wheat with mid-long, lax ears. The glumes are smooth and white. The grains are bold, hard and amber-coloured. It is slightly earlier than C. 591 in maturity. It is highly resistant to stem rust.

The variety has been found suitable for cultivation at high altitudes, viz., 10,000 ft. and above. This wheat is fast replacing the local strains in the Lahaul Valley in the Punjab.

C. 281

C. 281 (Plate 59) is a strain developed by the Punjab Department of Agriculture from the cross C. 591 × N.P. 4. It was released for general cultivation in 1955.

C. 281 is fully bearded with medium-long, lax ears. Glumes white and pubescent. Awns black and spreading at the time of maturity. Grains bold, hard and amber-coloured. They are lustrous and very attractive. Plants medium tall with moderate tillering. Maturity very early.

The variety is susceptible to rusts and loose smut. C. 281 is recommended for commercial cultivation for south-eastern districts of the Punjab where hot weather sets in earlier than usual. It also does well round about Delhi.

C. 273

C. 273 (Plate 59) is developed from the cross C. 591 × C. 209 by the Punjab Department of Agriculture.

The ears of this variety are fully bearded with white, pubescent glumes. Awns black. Grains hard, amber, bold, lustrous and attractive. Plants medium tall with good standing ability. Tillering good. Maturity medium late.

C. 273 shows fair degree of field resistance to yellow rust and tolerance to black and brown rusts. Susceptible to loose smut.

The variety was reported to perform particularly well under soils of average to high fertility. It is recommended for cultivation in East Punjab.

C. 253

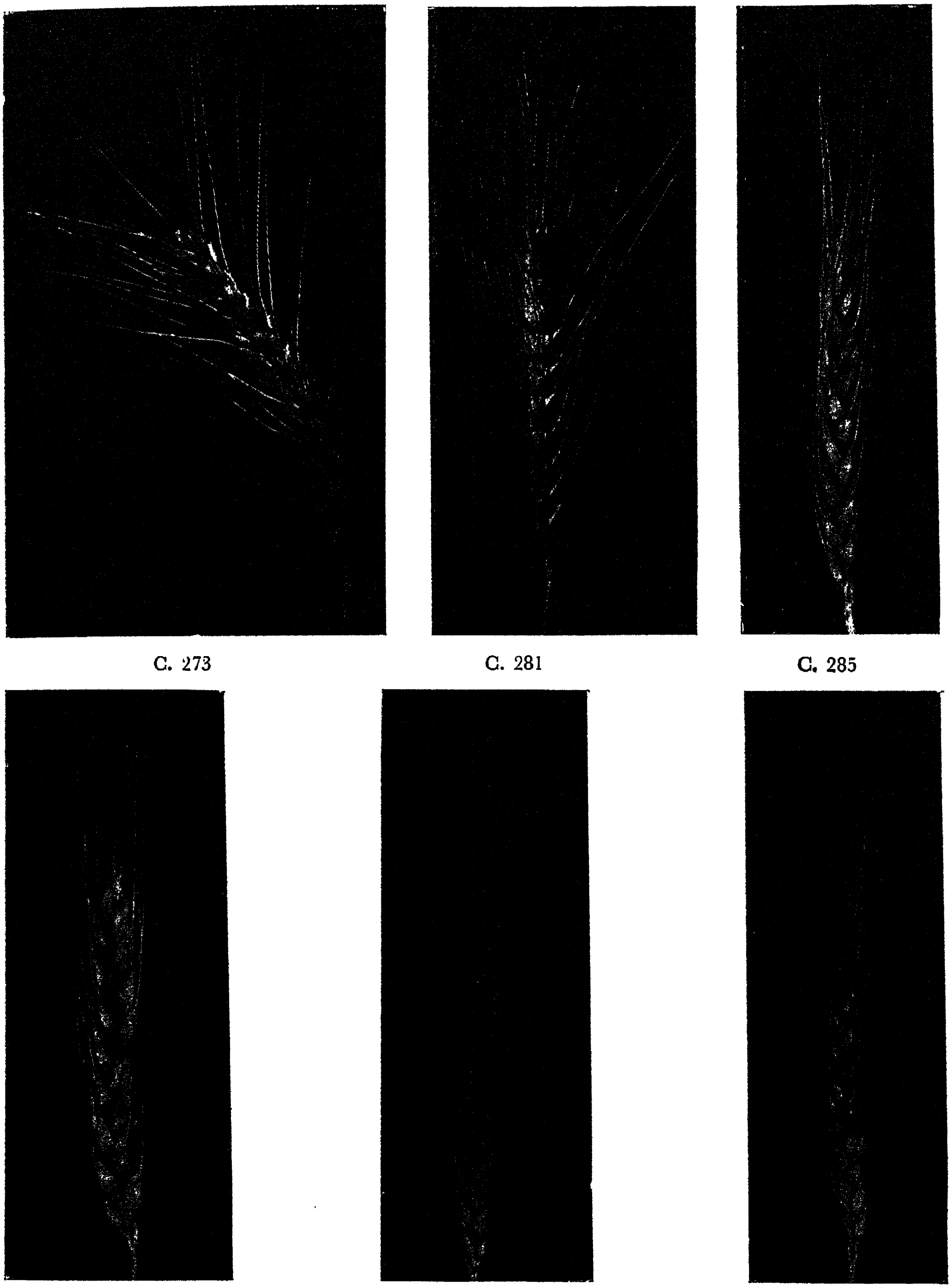
C. 253 was developed by the Punjab Department of Agriculture from the cross 25C × N.P. 165. It was released for cultivation in 1948.

C. 253 is a beardless wheat with white, glabrous glumes. Grains hard, amber and of medium size. Maturity medium late. Easily threshable. The variety is fairly resistant to yellow rust and loose smut in the field. Susceptible to black and brown rusts.

C. 253 is recommended for cultivation in the Kangra Hills of East Punjab.

C. 250

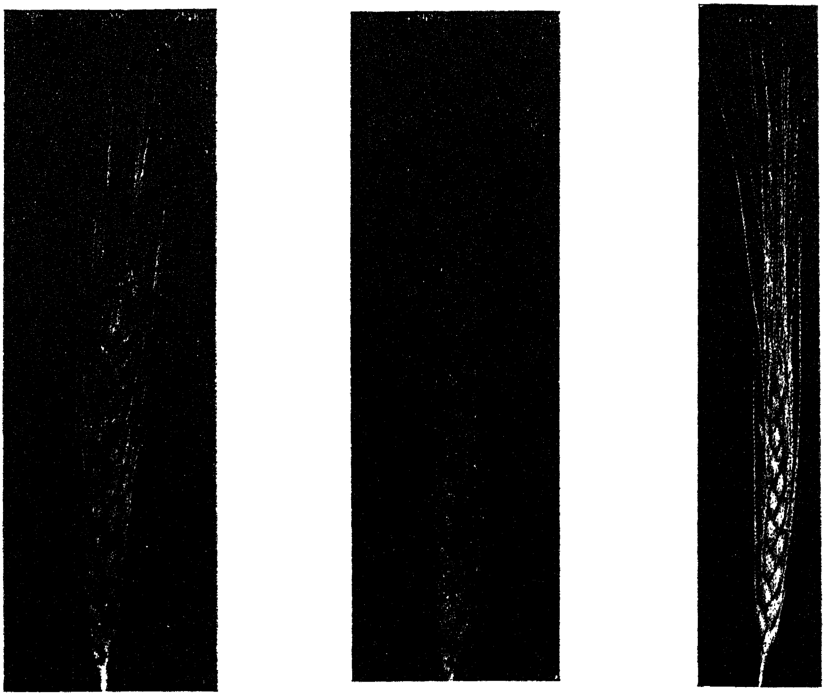
C. 250 is a sister selection of C. 228 developed from the cross 9D × Hard Federation by the Punjab Department of Agriculture. It was released for distribution in 1944.



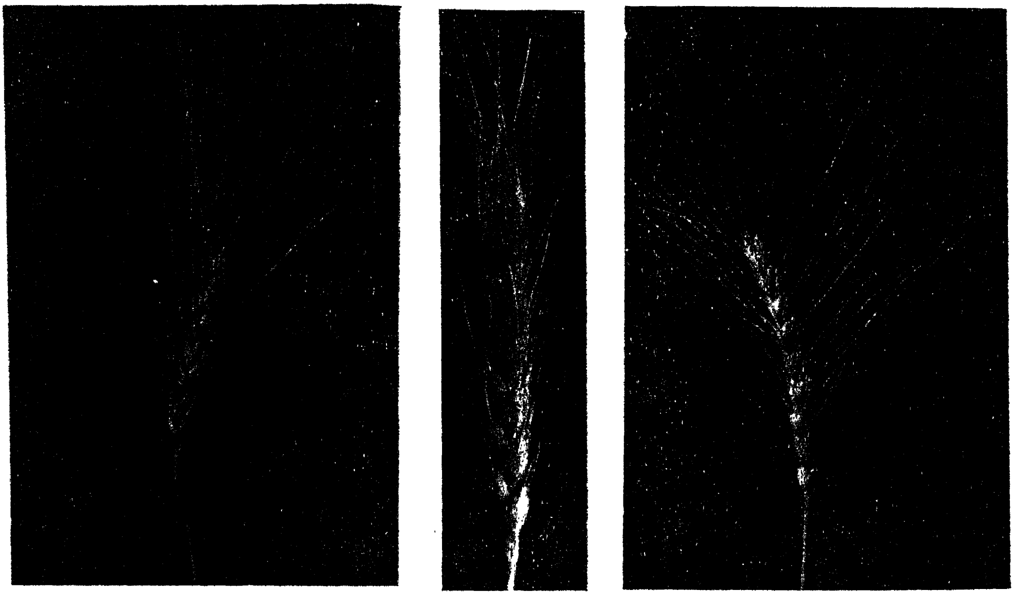
C. 273 C. 281 C. 285

C. 286 Hy. 11 Hy. 65

PLATE 59. Ears of C. 273, C. 281, C. 285, C. 286, Hy. 11 and Hy. 65



Hy. 38 Hy. 277 *Jay*



Vijay Niphad-4 Kenphad 25

Plate 60. Ears of Hy. 38, Hy. 277, *Jay*, *Vijay*, Niphad-4 and Kenphad 25

The strain is readily distinguished from the other wheats by its grassy appearance during early stages of growth. It is fully bearded with smooth, white glumes. Grains hard, bold and amber-coloured. Maturity medium late. Straw weak.

C. 250 is susceptible to black and brown rusts and fairly resistant to yellow rust. It is moderately susceptible to loose smut.

The variety is recommended for cultivation in the Gurdaspur and Kangra districts of East Punjab, where high humidity prevails.

C. 228

C. 228 (Plate 58) is a selection from the cross between Punjab Type 9D and Hard Federation, an Australian variety. It was developed by the Punjab Department of Agriculture, and released for cultivation in 1940.

C. 228 is fully bearded with lax ears and smooth, white glumes. The grains are very bold, hard and amber-coloured. It compares well with wheats from Manitoba which are known for their superior baking quality.

This is an early-maturing variety and fairly resistant to yellow rust. It is a variety recommended for late sowings under irrigated conditions in the Punjab.

C. 217

C. 217 (Plate 58) is a derivative from the cross C. 518×C. 516 developed by the Punjab Department of Agriculture. It was released for general cultivation in 1944.

It possesses short, compact ears and straw like C. 518. But unlike C. 518, it is well suited for cultivation under rainfed conditions. C. 217 is mid-late in maturity like C. 591. It is fully bearded with white, felted glumes. The grains are hard and amber-coloured. It is fairly tolerant to black rust.

This wheat is recommended for cultivation for *barani* sowings in the submontane areas of East Punjab.

Hy. 11

Hy. 11 (Plate 59) is a strain which resulted from the cross A.115× Kenya E. 220 at Powerkheda, Madhya Pradesh.

Hy. 11 is fully bearded. The ear is dense with white, smooth glumes. The ear sometimes exhibits a tendency for branching when grown under irrigated conditions. The grains are soft, white and of medium size.

This variety is resistant to black rust and is a popular wheat in the Narmada Valley of Madhya Pradesh. It is mid-late in maturity.

Hy. 38

Hy. 38 (Plate 60) was developed from the cross Ao.13×Kenya E. 220 at Powerkheda, Madhya Pradesh.

Hy. 38 is fully bearded with smooth, white glumes. The grains are white and soft. It is of medium maturity and tillers well. It is well suited for sowing under rainfed conditions. It is fairly resistant to black rust. This variety is recommended for cultivation in Malwa tract and the Narmada Valley in Madhya Pradesh.

Hy. 65

Hy. 65 (Plate 59) was derived from the cross [Bobin × (Bobin—Gaza)] × A.115 at Powerkheda, Madhya Pradesh. This is one of the very popular wheats grown in Madhya Pradesh and has been found particularly suitable for cultivation under irrigated conditions.

The variety has very impressive, thickset ears, which are fully bearded with smooth, white glumes. The grains are hard, bold, amber-coloured and attractive. It is resistant to black rust. It is medium early in maturity and can also be grown as a second crop after paddy or maize under irrigated conditions. Even under such condition yields up to 25 md. per acre have been reported. It yielded 73 md. per acre in one of the crop competitions in Madhya Pradesh.

Hy. 277

Hy. 277 (Plate 60) is a sister selection of Hy. 65 derived from the cross [Bobin × (Bobin—Gaza)] × A. 115, at Powerkheda, Madhya Pradesh.

Hy. 277 is a fully bearded wheat with white, smooth glumes. The grain is semi-hard, amber-coloured and of small size.

This variety is mid-late in maturity and resistant to stem rust. This has been recommended for cultivation in the northern districts of Madhya Pradesh. It does well both under rainfed and irrigated conditions.

Jay

Jay (Plate 60), also sometimes referred to as *Bansipalli* 808, resulted as a selection from the cross *Motia* (*T. durum*) × *Khapli* (*T. dicoccum*). This was developed by the Bombay Department of Agriculture.

Jay is fully bearded with smooth, white glumes. The grains are whitish yellow, hard, lustrous and bold.

It is a very early-maturing wheat which was released for general cultivation in 1934. It is extensively cultivated in the districts of Nasik, Nagar and Poona of Bombay State. The variety is susceptible to rusts but, because of its earliness, it escapes damage by black rust.

Vijay

Vijay (Plate 60), also known as Niphad-81, is a selection developed by the Bombay Department of Agriculture from a natural cross involving *Motia* (*T. durum*) and *Khapli* (*T. dicoccum*) as parents.

It is a fully bearded wheat with glabrous white glumes. *Vijay* resembles *Jay* in many respects. It is also a very early-maturing wheat with soft to semi-hard, white, bold grains. This was released for cultivation in 1939 and was popular in the districts of Nasik, Nagar and Poona of Bombay State.

Because of its extreme earliness the variety often escapes damage due to black rust.

Niphad-4

Niphad-4 (Plate 60) was derived as a selection from a cross [*Motia* (*T. durum*)

×*Khapli* (*T. dicoccum*)] × N.P. 4 (*T. aestivum*). The cross was made in the year 1933 at the Agricultural Research Station at Niphad, Bombay. It was released for general cultivation in 1942.

It is a fully bearded wheat with white pubescent, tough glumes. The ear is lax. The grains are very attractive, being whitish yellow, long and hard. It possesses good baking and milling qualities and gives sweet-tasting *chapattees*.

It is fairly tolerant to black rust but susceptible to brown rust and *Alternaria* disease. Because of the toughness of the glumes it is rather difficult to thresh. This has been a popular wheat of the irrigated tracts of the Deccan and Gujarat. It is now being replaced by Kenphad and other wheats.

Kenphad 25

Kenphad 25 (Plate 60) was developed from a cross made in 1942 between E. 144 and Niphad-4 at the Agricultural Research Station, Niphad, Bombay. It was released for general cultivation in 1951. Kenphad 25 was the first of the stem-rust-resistant wheats to be released in the Bombay State.

Kenphad 25 is fully bearded and the ear tapers towards the apex. Glumes are pubescent and brown. The grains are bold, yellow and hard. It is mid-early in maturity. Under field conditions it is resistant to most of the races of black rust. It is, however, susceptible to brown rust, loose smut and *Alternaria* leaf-spot disease. This has been found suitable for cultivation in Deccan and Gujarat areas.

N. 177

N. 177 (Plate 61) is one of the recently evolved wheats of the Bombay Department of Agriculture. It is a selection from the cross *Mondya* 417-5 × Hofed.

N. 177 is a fully bearded wheat with felted, white glumes and black awns. Grains hard, lustrous, bold and amber-coloured. Maturity early. It has wide adaptability and has been found suitable for cultivation in the irrigated tracts of Deccan and Gujarat.

It is resistant to stem rust and moderately so to *Alternaria* leaf-spot disease.

N. 345

N. 345 (Plate 61) is another recently evolved improved wheat of the Bombay Department of Agriculture developed from the cross *Mondya* 417-5 × Hofed.

N. 345 is fully bearded with brown, smooth glumes. The awns are brown in colour. Grains are hard, bold and amber-coloured. Maturity early. It is resistant to black rust.

This wheat has been recommended for cultivation in the districts of Baroda (Gujarat) and Nasik (Maharashtra).

C. 13

The present-day C. 13 (K. 13) is a reselection from the original awnless C. 13 developed in 1915 by the U.P. Department of Agriculture from a local wheat. The original C. 13 was developed by Leake in collaboration with the Howards.

C. 13 (Plate 62) is a fully bearded wheat with smooth white glumes. Ears long and lax. Grains amber, semi-hard and medium; straw weak. Maturity early.

The variety is very susceptible to all the three rusts and loose smut. It is reported to have given a maximum yield of 40 md. per acre.

C. 13 is recommended for cultivation in central U.P.

R.S. 31-1

R.S. 31-1 (Plate 62) was developed from the cross Pb. C. 591 × Rajasthan Local by the Rajasthan Department of Agriculture.

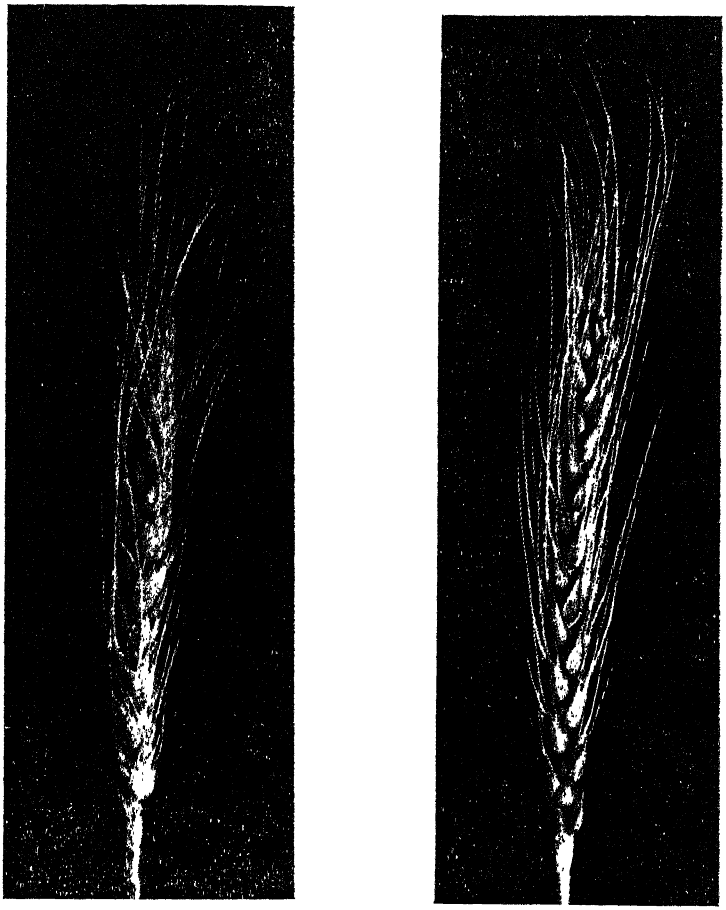
The variety is fully bearded with white, glabrous glumes. Grains amber, hard, lustrous and bold. Height medium. Maturity very early.

R.S. 31-1 is susceptible to all the three rusts. But, being very early, it is reported to often escape from the ravages of black rust. The variety is particularly found to do well in areas of average fertility and low soil moisture.

It is recommended for general cultivation for central Rajasthan consisting of Jaipur and Sawai Madhopur and some parts of Jodhpur and Durgapura.

REFERENCE

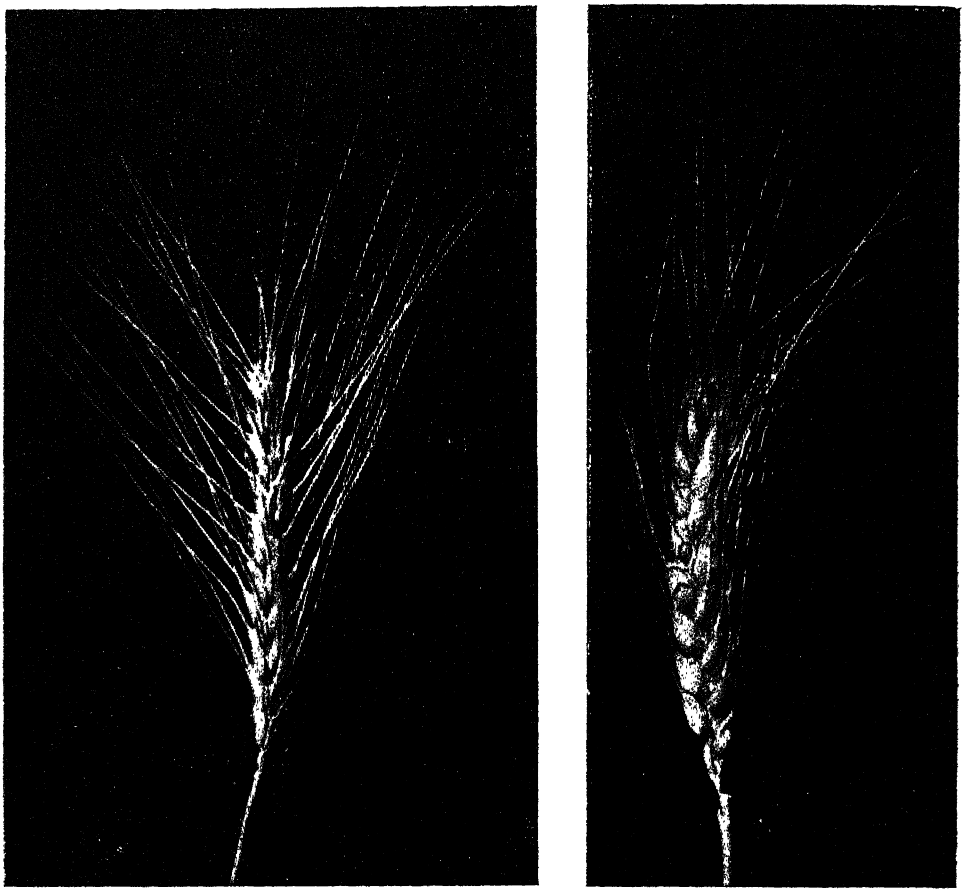
Pal, B. P., Murty, G. S. and Khan A. R. 1950. Registration of improved varieties in India. I. The New Pusa wheats. *Indian J. agric. Sci.* **20:** 165–72.



N. 177

N. 345

PLATE 61. Ears of N. 177 and N. 345



C. 13 R. S. 31-1

Plate 62. Ears of C. 13 and R. S. 31-1

VIII

GRAIN QUALITY

The quality of wheat is determined by a number of factors. The chemical composition of wheat, with reference only to its nutritional value and milling and baking quality, has been discussed here. As far as the nutritional value of wheat is concerned, besides starch it also supplies proteins, minerals and important vitamins.

The quality or the biological value of proteins is dependent upon their amino acid make-up. The usefulness of a particular protein in the body is determined by the extent to which it can furnish these amino acids, which are required for the building up and maintenance of muscles and the repair of worn tissues. Lack of certain amino acids in the diet consequently leads to malnutrition. Satisfactory diets must, therefore, contain proteins which are sufficient not only in quantity but also in quality. Amino acids are also the building materials of the important wheat protein, gluten. The amino acid composition of wheat and wheat products, therefore, deserves attention.

Minerals play an important part in the formation of bone, digestive juices, etc., and sufficient amount of both the major and micro-elements must be provided in the diet. Wheat is also an important source of these minerals.

The vitamins are required to ensure complete utilization of food. They are essential for various metabolic activities in the body as well as in building up immunity against diseases. Some of the more important water-soluble vitamins, such as thiamin, riboflavin and nicotinic acid, are dealt with in the following pages.

Voluminous literature has accumulated on different aspects of this subject and many papers which deserve attention have had to be omitted from the bibliography. An attempt has been made to summarize particularly the work done in India.

PROTEINS IN WHEAT

Wheat proteins are of special significance. Besides their importance in nutrition, they are principally concerned in providing the characteristic substance, gluten, which is so well known to millers and bakers. It is this particular substance which provides the structural framework for the familiar spongy, cellular texture of bread and a wide variety of other baked products. Flours considerably lacking in this protein are, therefore, never satisfactory for bread making.

Wheat essentially contains five different classes of proteins : (i) albumin, (ii) globulin, (iii) proteose, (iv) prolamin (gliadin), and (v) glutelin (glutenin). The gliadin and the glutenin are of special importance as these proteins, together with water and salts, form the well-known substance gluten. To form gluten both gliadin and glutenin are necessary. Glutenin is said to impart solidity to the gluten and gliadin, which is soft and sticky, to be responsible for the binding. The gliadin sticks to the glutenin and so prevents it being washed away in the process of washing out of the gluten.

The relation of gliadin to glutenin and the influence of different proportions of these two proteins in the flour upon its baking quality have been the subject of many investigations. Studies on the chemical nature of these two proteins of flour have shown that they are differently constituted. In recent years it has been possible to probe more closely into the chemical nature of different wheat proteins with the help of the new techniques of ultracentrifugation and electrophoresis.

A number of reviews, summarizing the nature of wheat proteins, have appeared in literature (Bailey, 1944; Blish, 1945; McCalla, 1949; Sullivan, 1954; Pence *et al.*, 1950).

The proteins of wheat are not, however, distributed evenly throughout the whole grain, as the bran and germ are richer in protein than is the endosperm. Even in the endosperm, it is possible that the centre is not so rich in protein as the outer portion. Some analyses indicating the composition of the various reductions in the mill which bear out this point are given in Table IX.

TABLE IX. ANALYSIS OF MILL STREAMS (Kent-Jones and Amos, 1959)
(Results calculated on 13·5% moisture basis)

Flour	Moisture %	Ash %	N %	Protein % N×5·7	Dried gluten %	Character of gluten	Maltose after 1 hr. 27°C %	Fat %	Starch %	Cellulose %
Straight run	14·41	0·41	1·92	10·94	11·98	Fair	2·11	1·28	68·0	0·36
Lower grade	14·48	0·49	1·94	11·06	12·02	Fair	1·99	1·36	68·3	0·41
Fines	14·74	0·39	1·82	10·36	11·14	Fair	2·20	1·16	72·5	0·23
1st break	15·34	0·54	2·05	11·68	13·00	Soft	1·80	1·13	70·0	0·20
2nd break	15·54	0·56	2·36	13·45	14·80	Soft	1·50	1·30	67·0	0·40
3rd break	15·26	0·70	2·83	16·16	18·20	Very soft	1·28	1·94	64·9	0·25
Bran	15·50	5·13	2·26	12·89	—	—	1·65	2·94	—	12·64

Protein content. The protein content of American wheats has been extensively surveyed and is reported to vary approximately from 7 to 24 per cent (Hegsted *et al.*, 1954). Results of a survey of thousands of wheats passing through the Minneapolis market have been summarized by Bailey (1944). Crude protein of hard spring wheat ranges from about 10 to 20 per cent. The mean value was about 12 per cent between 1925 and 1928 but increased to about 14·5 per cent between 1929 and 1938. Soft red winter wheats and white winter wheats are reported to be low in protein content and average about 10±0·7 per cent.

Extensive information on Indian wheats is not available. A survey of protein content in Indian wheats was, for the first time, taken up at the Agricultural College and Research Institute at Lyallpur (Punjab, in undivided India) in 1939 under a scheme to test the milling and baking qualities of Indian wheats. An extensive survey was done in pre-partition India of wheats grown in the North-West Frontier Province, Sind, the Punjab, Central Provinces and Berar, Bombay, Bihar, Gwalior State and United Provinces. Large number of samples of wheat grown under unspecified conditions were collected from different parts of the country and wheat protein survey maps were prepared for Bombay, Bihar, Central Provinces and Berar, North-West Frontier Province and Sind. For the purpose of comparison, protein levels were divided into three categories designated as low (below 8 per cent), medium (8·0 to 10·9 per cent) and high (above 10·9 per cent). The level of wheat protein was reported to be high in the southern parts of Bombay and Bihar. The average protein content of wheats grown in Bombay was also of a high order ranging from 10·4 to 12·4 per cent. Similar high values were also recently obtained with wheats grown at Niphad which varied from 11·0 to 17·4 per cent (Banerjee and Das, 1957); this may be due to the nature of the Bombay soil. The protein content of wheat is largely dependent on the nature of the soil. Heavy soils are reported to give wheats of a high protein content compared to wheats on light soils (Teakle, 1952).

Subsequent work on the determination of protein content of Indian wheats was taken up at the Indian Agricultural Research Institute, New Delhi, in 1953 under a scheme financed by the Indian Council of Agricultural Research (*Final Rep., I.A.R.I.*, 1957). The work was taken up with the limited scope of analyzing 14 varieties of Indian wheats raised in three replications under comparable conditions of growth at Delhi and at Pusa (Bihar) over a period of three consecutive years. The varieties selected for the purpose were N.P. 4, N.P. 52, N.P. 125, N.P. 165, N.P. 710, N.P. 718, N.P. 737, N.P. 758, N.P. 760, N.P. 761, N.P. 770, N.P. 775, C. 591 and K. 13. A basal dressing of 20 lb. N as ammonium sulphate and 40 lb. P_2O_5 as superphosphate was used for all wheats at both the places. The protein content of these wheats grown at Delhi varied from 8·8 to 11·2 per cent, 9·4 to 12·1 per cent and 7·6 to 10·4 per cent in 1953, 1954 and 1955 respectively. The protein content when grown at Pusa (Bihar) during the corresponding years varied from 9·2 to 12·1 per cent, 10·0 to 13·8 per cent and 11·4 to 14·6 per cent respectively.

On an average, the protein content was significantly higher at Pusa than at New Delhi. It was particularly so during the third year. The interaction between places and years was also significant.

The average differences between varieties were highly significant unlike the observations reported by earlier workers (Shollenberger *et al.*, 1949; Cook and Farquhar, 1946), who reported that under the same environments different varieties of wheat do not show wide variation in protein content.

The average protein content of Indian wheats grown in different parts of the country is reported to range between 8·0 and 10·8 per cent in the *Report on the Marketing of Wheat in India, 1937.* The average protein content of the Punjab wheats is reported to be 10·36 per cent, the range of variation being 8·06 to 12·43 per cent (Rattan Singh and Bailey, 1940).

The protein content of wheat is largely dependent upon the environment—climate and soil being the principal determinants. The chief climatic factors are rainfall, humidity, temperature, day-length and length of the ripening period. The composition of the soil and the nutrients supplied for the plant growth have predominating influence on the protein content of the grain. The availability of nitrogen to wheat, particularly at the later stages of the growth and during the reproductive phase, increases the protein content of the grain (Finney, 1951; Thorne and Watson, 1955). The beneficial effect of nitrogenous fertilizers on the protein content of wheat has also been observed by other workers. Protein content of wheat is found to be more if the crop is grown with the application of ammonium sulphate or green manure or with a legume in the rotation (Champlin and Wall, 1947; Hunt *et al.*, 1950; Chandrasekhara *et al.*, 1953; Gupta and Das, 1954b).

An increase of grain protein as a result of late application of nitrogen by spraying urea on the wheat leaves has also been observed by Sadaphal and Das (1956a). The maximum increase in wheat protein was observed by spraying 6 per cent urea thrice. Increasing the frequency of spray did not result in a corresponding increase in the grain protein, except at concentrations of 6 and 9 per cent when the crop was grown with a basal dressing of NPK fertilizers. Spraying at concentrations as low as 1 per cent urea, in the absence of basal dressing of NPK on the other hand, resulted in a significant increase in the protein content.

Phosphatic fertilizers generally depress the protein content of the grain (Teakle, 1952; Gupta and Das, 1954b).

Besides the major nutrients, micro-nutrients have also been reported to influence the content of protein. Fertilization of the soil with either zinc or manganese resulted in a significant increase in the protein content of wheat, the maximum increase being with the manganese treatment. Foliar application of zinc, copper and magnesium but not of manganese showed similar effect (Sadaphal and Das, 1956b).

The effect of simultaneous variation in the dose of nitrogen and irrigation on wheats was studied at Lyallpur. The experiment was done on two varieties (C. 591 and C. 518) with three doses of nitrogen (0, 25 and 50 lb. N per acre in the form of ammonium sulphate) and three frequencies of irrigation. On the average of all the frequencies of irrigation, increase in nitrogen dose significantly increased the protein content of wheat. There was a gradual decline in the protein content of both the varieties with gradual increase in the number of irrigations (Anon., 1946, 1947).

Sixteen varieties of wheat grown at the Government Research Farm, Kanpur, during 1957-58, were analyzed for their total protein content which varied from 10·8 to 17·5 per cent. Pb.T. 9D, C. 13 and N.P. 710 contained 17·5, 17·1 and 16·1 per cent protein respectively (Mehta *et al.*, unpublished).

Gluten. Gluten is that portion of wheat protein which is responsible for providing the framework for the spongy texture of bread and other baked products. In spite of extensive investigations on the chemical nature of gluten, no satisfactory explanation has emerged for its physical behaviour or for variations in the physical properties that appear responsible for wide variations in different wheats. On dry basis gluten consists of 75 to 85 per cent protein and 5 to 10 per cent lipids, the remainder being starch. The lipid appears to be in combination with protein in a manner typical of lipo-proteins. The lipids are reported to participate to a considerable extent in determining dough structure. Some evidences now show that the lipids are involved in improved action.

Gluten is generally regarded as a mixture of equal parts of gliadin and glutenin. But these terms are not appropriate since they do not signify any definite chemical substance. These terms have been retained for the sake of convenience. Gliadin refers to that portion of gluten which is soluble in 60 per cent aqueous alcohol and glutenin to the remainder which is insoluble in neutral solvents but soluble in acidic or alkaline solvents.

Pence *et al.* (1951) found that approximately half of the total albumin and nearly all the globulins of the flour may be retained by crude gluten when washed from doughs using a 0·1 per cent phosphate buffer at pH 6·8. Even vigorous washing by means of a mechanical blender fails to remove more than half of the soluble proteins from the gluten, which suggests a binding of the soluble proteins to the gluten during dough making. Separation of soluble proteins from gluten results in its granular form. The soluble proteins appear to exert considerable modifying effect on the properties of gluten. Baking properties of crude glutens obtained from flours of widely varying properties were rather similar when soluble fractions were omitted from reconstituted doughs. Original differences in quality were restored when the soluble materials were added back to the gluten and starch doughs (Finney, 1943; Pence *et al.*, 1951).

Many cereal chemists believe that crude gluten may not represent the condition or composition of proteins in the original flour. Hess (1955) presented quite convincing evidence that gluten proteins occur in flour in a much different form than in crude gluten.

A structural chemical alteration of flour protein appears to be caused by mechanical influences during the conversion of the proteins to gluten.

The amino acid composition of crude gluten is known and the usual amino acids account reasonably well for the nitrogen present. However, the amino acid composition of crude glutens from a wide variety of flours is fairly uniform and fails to reflect differences in dough characteristics or baking quality of flours (Pence *et al.*, 1950).

It is apparent that the quality rather than the quantity of gluten present in wheat flour determines its baking quality. The gluten content of Indian wheats has been found to vary considerably. Rattan Singh and Bailey (1940) reported a variation of 6·8 to 11·3 per cent. Banerjee and Das (1954) reported a variation of 6·8 to 13·9 per cent in Indian wheats. Some of the Niphad wheats grown in Maharashtra are low in gluten content in spite of their higher content of protein.

Fourteen Indian wheats grown in triplicate under comparable conditions of growth at New Delhi and at Pusa (Bihar) over three consecutive years showed a variation from 5·1 to 10·5 per cent gluten content. The average varietal difference in this respect was highly significant. Moreover, average gluten content was also found to be significantly higher in wheats grown at Pusa than in those grown at New Delhi (*Final Rep., I.A.R.I.*, 1957).

✓ **Amino acid composition of wheat proteins.** The amino acid composition of wheat and wheat products has received considerable attention not only because of its importance in nutrition but also because of the implications for the quality of gluten. McElroy *et al.* (1949) using pure wheats have shown that considerable variations exist in their amino acid composition with particular reference to the content of lysine, arginine, valine and phenylalanine. Soil and climatic conditions on the other hand did not show any significant effect on the amino acid composition. Proteins in different parts of wheat are known to differ in their amino acid composition (Table X).

TABLE X. AMINO ACID COMPOSITION OF WHEAT PROTEIN CALCULATED TO 16·0 GM. OF NITROGEN (Block and Bolling, 1951)

Amino acid	Wheat bran	Wheat flour	Wheat germ	Wheat whole	Wheat gluten
			gm.		
Arginine	7·5	3·9	6·0	4·3	3·9
Histidine	1·7	2·2	2·5	2·1	2·2
Lysine	3·9	1·9	5·5	2·7	2·0
Tyrosine	—	3·8	3·8	4·0	3·8
Tryptophan	1·3	0·8	1·0	1·2	1·0
Phenylalanine	3·0	5·5	3·0	5·1	5·5
Cystine	1·5	1·9	1·4	1·8	1·9
Methionine	1·3	2·0	1·3	2·5	1·5
Threonine	2·5	2·7	6·3	3·3	2·7
Serine	5·3	4·3	—	4·3	—
Leucine	6·5	7·0	6·7	7·0	7·5
Isoleucine	4·5	4·2	4·5	4·0	3·7
Valine	4·1	4·1	4·3	4·3	4·2
Glutamic acid	—	—	—	29·0	—

The proteins of the endosperm have lower lysine content than those of germ and bran. Pence *et al.* (1950) also indicated that gluten had a low lysine content.

Feeding experiments have shown that wheat protein is deficient in the amino acid lysine. Many investigators have shown that supplementing wheat products with lysine results in an improvement of their protein quality (Hutchinson *et al.*, 1956a, b; Sure, 1957; Deshpande *et al.*, 1957; Rosenberg, 1957). The practicability of breeding wheat varieties with improved lysine level in the protein and at the same time having other desirable characteristics deserves attention. It, of course, depends upon the existence of breeding material with above-normal lysine. Taranova (1951) reported that the Russian wheat, Novo-Ukrainka 38, has a markedly higher lysine content. Recently, Lawrence *et al.* (1958) screened a number of wheat varieties and species for their lysine content and explored the possibility of obtaining wheats of higher lysine content through breeding. The lysine content in different American wheats is reported to vary from 2·46 to 3·84 per cent of the protein, while still wider variations are seen among other *Triticum* samples.

Some of the Indian wheats have been analyzed for their amino acid content. Methionine content of the few Indian wheats studied was found to vary from 0·22 to 0·34 per cent (Gupta and Das, 1954a). Lysine content varied from 0·3 to 0·37 per cent (De, 1951; Chitre, 1953; Chitre *et al.*, 1955).

About 20 to 30 per cent of the initial amount of lysine present in flour is reported to be lost in the course of ten months' storage (Anon., 1951).

VITAMINS

Thiamin. Thiamin is one of the vitamins which has been most studied. This is partly because of its relative importance in nutrition and partly because of its unstable nature.

Thiamin content of wheat is reported to vary considerably among varieties (Bailey, 1944; Robinson *et al.*, 1949). Work done abroad shows that the mean value of this vitamin in wheat is probably about 5 μg./gm., the range being from 4 to 10 μg./gm. Downs and Cathcart (1941) reported that 90 per cent of the samples of hard wheats possess 5 to 9 μg./gm. thiamin. The values reported by these authors are somewhat high as compared to those reported by many others.

An extensive study of thiamin content of Indian wheats has also been made (Ahmad *et al.*, 1948; Guha, 1953; Hashmi *et al.*, 1954; Chitre *et al.*, 1955).

Ahmad *et al.* (1948) reported a variation of 2·65 to 5·73 μg./gm. of thiamin in Indian wheats, the softer wheats showing lower values (2·65–3·33 μg./gm.) and the hard wheats higher values (3·84–4·84 μg./gm.). Thiamin content of different fractions of wheat grain, separated in the process of milling, was also studied. Nearly 50 per cent of the total thiamin of wheat is present in white shorts, a layer covering the endosperm and lying just below the aleurone, while over 20 per cent is in the endosperm itself and over 17 per cent in the germ. *Atta*, which is a coarse flour of 95 to 97 per cent extraction and which constitutes the chief product of wheat in this country, was investigated in some detail. It was found that 26·0 to 29·9 per cent thiamin was lost in its preparation. The loss was much more than can be accounted for by the removal of some thiamin-rich fractions of the grain. It was suggested that the heat developed in stone mills during grinding was responsible for the destruction of much of the thiamin. The thiamin content of different types of Indian bread was also investigated. The preparation of *chapattee* was found to result in a loss of 12·3 to 33·3 per cent of thiamin; wheats with high thiamin content lost a higher percentage. Since some of the thiamin is lost in the preparation of *atta*, the *chapattees* retain only about 47 to 64 per cent of the original thiamin of wheat.

Loss of thiamin during grinding by different methods, such as by hand *chakki*, *gharat* (water-driven *chakki*) and power-driven *chakki*, was also studied at Lyallpur (Anon., 1946, 1947). *Atta* ground with hand *chakki* showed the least loss of thiamin while that ground with power-driven *chakki* recorded the highest loss. *Atta* ground by *gharat* was about the same as that ground by hand *chakki* in this regard.

Guha (1953) analyzed a large number of wheats grown at Kanpur, New Delhi and West Bengal and reported variation in thiamin content from 2·0 to 6·7 μg./gm. Chitre *et al.* (1955) analyzed 13 samples of wheat for thiamin which varied from 1·64 to 4·75 μg./gm.

Gupta and Das (unpublished) also evaluated a few wheats for their thiamin content by the microbiological method, which agreed with the results obtained by the thiochrome method. The reported variation was from 4·14 to 5·15 μg./gm.

Evidences are accumulating to indicate that thiamin content of wheats is dependent upon the genetic make up as well as the soil and climate. McElroy *et al.* (1948), and Spencer and Galgam (1949) found soil types to have an important effect on the thiamin content while Johannson and Rich (1942), and Robinson *et al.* (1949) failed to note any such effects.

Phosphatic fertilizers alone or in combination with other fertilizers have been observed to increase the thiamin content of wheat. Farmyard manure, rape cake and green manure have all shown similar effects (Gupta and Das, 1956; Chandrasekhara *et al.*, 1953). Similar findings with phosphatic fertilizers were also obtained by Hunt *et al.* (1950), though Bains (1953) did not get any significant effect.

Riboflavin. Wheat is a rich source of riboflavin. Andrews *et al.* (1942) reported variation in the content of this vitamin in different wheats while Robinson *et al.* (1949) failed to observe any such differences. There appears to be little influence of the soil type on the content of this vitamin in wheats. Andrews (1943a, b) and Robinson *et al.* (1949) did not find any variation in riboflavin content of wheats when grown in different soil types.

Nearly all investigators agree that wheat contains approximately 1 μg./gm. of riboflavin. Soft wheats probably have slightly lesser quantity of riboflavin than hard wheats, the usual range being 0·8 to 2·0 μg./gm. (Hegsted *et al.*, 1954). Barton-Wright (1942) reported some values as high as 3·7 μg./gm. and mean values of 2·6 and 2·9 μg./gm. for English and Manitoba wheats respectively. Extensive studies on improved methodology for the determination of riboflavin have been made by Slater and Morrell (1946).

A number of Indian wheats were analyzed for their content of riboflavin using different methods. Estimating with the help of the microbiological method, Gupta *et al.* (1953) reported a variation from 0·97 to 1·18 μg./gm. In a subsequent study also similar variation of 1·01 to 1·17 μg./gm. was found (Das *et al.*, 1953).

Chitre *et al.* (1955) following the method of Slater and Morrell reported a variation of 0·91 to 2·92 μg./gm. in 13 Indian wheats.

Fourteen Indian wheats grown in triplicate under comparable conditions at the Indian Agricultural Research Institute, New Delhi and its substation at Pusa (Bihar) were analyzed for their riboflavin content. This varied from 0·78 to 1·18 μg./gm. and from 0·96 to 1·23 μg./gm. at New Delhi and at Pusa respectively. The average varietal difference between 14 varieties tested was found to be highly significant. N.P. 710 gave significantly the highest value, followed by N.P. 165 and N.P. 758, considering their performance at New Delhi and Pusa. The average content of this vitamin was found significantly higher in the wheats grown at Pusa (Bihar) than in those grown at Delhi. The interaction between variety and place was also highly significant. N.P. 737, N.P. 758 and N.P. 710 occupied the first three places at Pusa, while N.P. 165, N.P. 710 and N.P. 758 secured similar ranks at New Delhi (*Final Rep., I.A.R.I.*, 1957).

Studies on the content of riboflavin in wheat and the effect of different factors on it have received inadequate attention so far. Some evidences are available to show that mineral fertilizers tend to increase the content of this vitamin in wheat (Gupta and Das, 1956).

Nicotinic acid. Nicotinic acid is one of the important members of the B vitamin complex. Nutrition surveys conducted in this country have shown that a major portion of the requirement of nicotinic acid is derived from cereal grains which are relatively rich in this vitamin. Maize and oats are poor, rice and barley are better while wheat is the best source of nicotinic acid (Klatzkin *et al.*, 1948). The variation in the content of this vitamin among wheat varieties is large and it is said to be associated with the genetic make-up of wheat (Teply *et al.*, 1942).

The nicotinic acid content of wheat is relatively high and is in the region of 60 μg./gm. English wheats contain about 50 μg./gm. and Manitoba wheats about 72 μg./gm. Barton-Wright (1942) reported the value for English wheat and Manitoba wheat as 48 and 55 to 66 μg./gm. respectively. Teply *et al.* (1942) reported figures for wheats varying from 47 to 106 μg./gm., most samples containing 50 to 60 μg./gm. and average value being 60·1 μg./gm.

Chaudhuri and Kodicek (1950) demonstrated the presence of a nicotinic acid precursor in wheat which may be converted to nicotinic acid in the milling process. The role of such material in nutrition has not been fully realized. The bound form of nicotinic acid called ' Niacinogen ' has been isolated from rice and wheat brans in a crystalline form (Guha, 1957).

Nicotinic acid content of Indian wheat varieties was estimated by the microbiological as well as chemical methods. The values obtained by the different methods agreed well. The variation in different wheats as estimated by Chaudhuri's method was 33·5 to 48·5 μg./gm. (Prasad *et al.*, 1953).

Nicotinic acid content of wheats grown in Niphad (Maharashtra) was found to vary from 29·5 to 58·4 μg./gm. It was also appreciably higher in wheats grown under irrigated conditions than in those grown under dry conditions (Banerjee and Das, 1957).

Rattan Singh *et al.* (1956) studied the effect of soils on the content of nicotinic acid in wheat. For the same variety of wheat, nicotinic acid content of grain was found to be higher in the crop grown on alluvial soil compared to that grown in black and red soil zones. The difference was statistically significant.

Green manuring has been found to increase nicotinic acid content of wheat grains (Gupta and Das, 1956).

Studies with the use of microbiological method for the assessment of nicotinic acid content in different Indian wheats have shown variation ranging from 33·3 to 45·8 μg./gm., the average value being 40·8 μg./gm. (Das *et al.*, 1953).

Fourteen Indian wheats grown in triplicate under comparable conditions at New Delhi and at Pusa were also analyzed for their nicotinic acid content (*Final Rep., I.A.R.I.*, 1957). Among varieties the content of this vitamin varied from 49·2 to 64·3 μg./gm. and from 43·3 to 64·1 μg./gm. during 1953 and 1954 when grown at New Delhi and from 48·0 to 61·0 μg./gm. and from 57·6 to 72·5 μg./gm. during the same respective years when grown at Pusa (Bihar). In these studies the difference between varieties was highly significant. N.P. 737 gave significantly the highest nicotinic acid content followed by N.P. 4, N.P. 125, K. 13 and N.P. 770. On an average, the niacin content was significantly higher at Pusa than at New Delhi. The average content of this vitamin in the two years differed significantly, thereby indicating the influence of season. The interaction between varieties and places was also significant. N.P. 737, N.P. 4 and N.P. 770 secured the first three places at Pusa, while K. 13, N.P. 125 and N.P. 737 secured the same respective places at New Delhi (*Final Rep., I.A.R.I.*, 1957).

The loss of nicotinic acid in *atta* during grinding by different methods was studied at Lyallpur (Anon., 1946, 1947). The loss is reported to be about 50 to 55 per cent if *atta* is prepared by using *gharat* (water-driven mill), hand-driven *chakki* or power-driven *chakki* and about 30 per cent if roller mill is used for this purpose.

SUGARS

Flours contain small and important quantities of sugars and substances intermediate between starch and sugars. The exact nature of all these substances is not known.

By the recent chromatographic technique wheat flour has been found to contain glucose, fructose, sucrose, maltose, raffinose and a series of oligosaccharides composed of D-fructose and D-glucose called gluco-fructosans. Recent studies have revealed that the true sugar content of wheat flour is about 1/10 of that indicated by conventional methods. The discrepancy is principally due to the gluco-fructosans, which, like sucrose, hydrolyse readily with acid. The total gluco-fructosans content of wheat flours is about 1 per cent (Koch *et al.*, 1951).

It has now been possible not only to determine the nature of carbohydrate in a single wheat germ but also to analyse separately the embryonic plant and scutellum sections of the germ for sugars. The carbohydrates present in wheat germ are principally raffinose and sucrose with a trace of glucose (Montgomery and Smith, 1956).

Total reducing sugars originally present in 30 different varieties of Indian wheats were found to vary from 0·28 to 0·49 per cent (Banerjee and Das, 1954).

FAT

Wheat flour contains a small amount of fat or an oil characteristic of wheat. The fat is chiefly present in the germ. Wheat fat, like other fats, tends to undergo changes, such as oxidation, and consequently becomes rancid. For this reason the milling engineer takes the trouble of excluding as much fat or oil as possible from white flour.

The content of ether extract in Indian wheats grown under comparable conditions in triplicate at Delhi and at Pusa for a period of three consecutive years has been found to vary from 0·97 to 2·28 per cent (*Ann. Rep., I.A.R.I.*, 1957). Similar variation in fat content was reported earlier. Common bread wheats grown under irrigated conditions show higher fat content compared to those grown under dry conditions (Das *et al.*, 1954; Banerjee and Das, 1957).

PHYTIC ACID

Phytic acid is a compound formed by the union of one molecule of inositol with six molecules of phosphoric acid. If phytic acid is ingested, it combines with the calcium and iron in the diet to form almost insoluble compounds that are not readily absorbed in the alimentary canal. High phytic acid content is, therefore, undesirable in foodstuffs. The total quantity of phytin or of other salts of phytic acid present in wheat varies with the variety of wheat and other factors. Major portion of the salts of phytic acid is present in the bran and the germ and relatively little occurs in the endosperm (Table XI). Phytic acid content of flour increases as the extraction is raised.

TABLE XI. PHYTIC ACID CONTENT OF WHEAT AND WHEAT PRODUCTS (Kent-Jones and Amos, 1959)

		Phytic acid phosphorus mg./100 gm.
Wheat		170–320
Bran		750–1,200
Germ		500–600
Flour :	72 % extraction	25–50
	85 % ,,	105–130
	100 % ,,	200–300

Pasternak (1903) reported that phytin phosphorus constitutes 70 to 90 per cent of the total phosphorus of the wheat grain. Similar observations were reported by Andrews and Bailey (1932), Knowles and Watkin (1932), and Harris and Mosher (1934).

The phytin phosphorus content of 14 Indian wheats varied from 257 to 375 mg./100 gm. and from 250 to 376 mg./100 gm. at New Delhi during 1953 and 1954 respectively. At Pusa, the same wheats grown under comparable conditions showed phytin content of 161 to 276 mg./100 gm. and 237 to 330 mg./100 gm. for the two successive years (*Final Rep.*, *I.A.R.I.*, 1957).

The phytin phosphorus content of wheat is reported to be increased by the application of phosphatic fertilizers. The grains from plots treated with superphosphate in conjunction with ammonium sulphate are reported to show the highest content of phytin phosphorus (Bains, 1949). The content of phytin phosphorus in wheat grains from crops raised with different manures and fertilizers is found to be the lowest for plots receiving green manure and highest for plots receiving complete mineral fertilizers (Srivastava *et al.*, 1955).

MINERAL MATTER

The mineral matter in flour is not large in quantity but it may have a considerable effect on the quality and behaviour of the flour. The nature of doughs prepared from wheat flour is considerably influenced by the cations present. The percentage of mineral matter present in a flour usually gives a useful indication of the grade of the flour.

The percentage of different elements in wheat and the flour fractions is dependent upon the soil. The distribution of the mineral constituents in wheat has been summarized by Beeson (1941) and Booth *et al.* (1941).

Early work at the Ohio station by Ames and co-workers indicated that added fertilizers influence the mineral composition of wheat ash. Gericke (1933, 1934) showed that the amount of available nitrogen in the soil influenced the protein content of wheat. He also demonstrated with wheat grown in tank culture that the chemical composition of the grain varied depending on the stage of growth at which mineral nutrients were available to the plants.

The ash content of Indian wheats varies from approximately 1·7 to 2·3 per cent and the phosphorus, calcium and iron contents vary from 302 to 500 mg./100 gm., 54 to 88 mg./100 gm. and 4·9 to 7·8 mg./100 gm. respectively. The differences in the contents of phosphorus and iron in Indian wheats were highly significant. This was not so for the calcium content. On an average, the contents of phosphorus and calcium were significantly higher in wheats grown at New Delhi than those grown at Pusa (Bihar), thereby indicating the influence of soil and environment on the content of these minerals in wheat (*Final Rep., I.A.R.I.*, 1957).

The ash content of wheats grown in Niphad (Maharashtra) was found to be lower than that of the N.P. wheats grown at New Delhi (Banerjee and Das, 1957).

Fertilizer treatments have been found to influence the mineral composition of wheat (Gupta and Das, 1954b; Srivastava *et al.*, 1955). Phosphatic fertilization resulted in a significant increase in total phosphorus in the grains. Application of superphosphate, either alone or in conjunction with other inorganic fertilizers or green manure, showed a significant increase in all the forms of phosphorus. Farmyard manure application, on the other hand, did not show any change in the total and phytin phosphorus, although rape cake, which does not increase the total phosphorus, markedly increased the phytin phosphorus. Green manuring alone shows a decrease in total phytin and inorganic phosphorus, while content of acid-soluble phosphorus remains practically unaffected.

Bains (1949) also reported that superphosphate treatment increased the total phosphorus content of wheat. The application of various fertilizers with green manure also produced grains with comparatively high content of calcium and total phosphorus.

EFFECT OF MILLING

The effect of milling upon the composition of wheat products is largely dependent upon the structure of the kernel and the parts removed by various degrees of milling. The following layers in the kernel and their approximate thickness may be distinguished: outer pericarp, 45 to 50 μ; testa and hyaline layer, 10 to 15 μ; aleurone layer, 65 to 70 μ; and starchy endosperm (Hegsted *et al.*, 1954). The germ is separated from the rest of the kernel by the scutellum, and the germ proper may be divided into the shoot and root of the embryo (Fig. 8). Recent studies on the dissection of the kernel by various methods into the morphologically defined parts by Shetlar *et al.* (1947), Shetlar (1948) and Hinton (1947) and analysis of the fractions thus obtained have yielded data summarized in Table XII (Data from Hegsted *et al.*, 1954).

The concentration of almost all the constituents, other than starch, is greater in the outer layers and in the germ. More detailed studies on niacin distribution have recently been done by Heathcote *et al.* (1952).

The composition of the kernel has also been studied by the examination of various milling fractions obtained either by special or commercial milling procedures. This procedure is of more practical importance but is not intelligible to those not well acquainted with milling procedures, since the names of the mill streams are not familiar and milling procedures often vary. Bailey (1944) summarized much of the available data. When referred to flour of different degrees of extraction the results are of more significance in human nutrition. The results of extensive studies carried out by McCance *et al.* (1945) are given in Table XIII.

Similar data have also been reported by others (Hintzer *et al.*, 1949). The typical distribution of thiamin in outer layers of the grain is evident while the distribution of protein, fat, fibre, niacin and phytic acid phosphorus is also similar. The loaf volume, as determined by McCance *et al.* (1945), showed large reduction at extractions of flour above 80 per cent. This fact, combined with the high concentration of thiamin present in the outer layer of the grain, suggested the selection of approximately 80 per cent extraction when a compromise between baking quality and nutritional value is desired. This fact will be evident from Fig. 9.

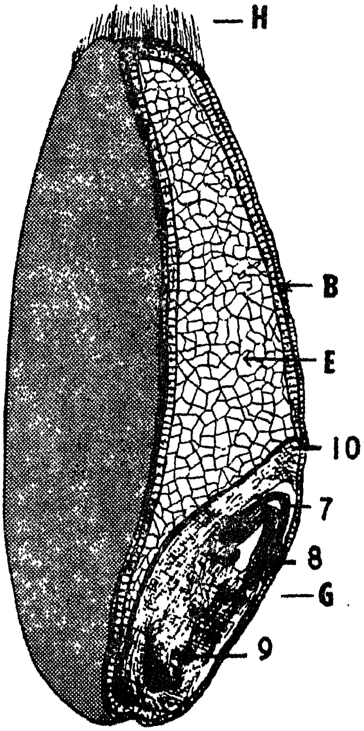


FIG. 8. Structure of the wheat grain
The scutellum (10) separates the endosperm (E) from the germ (G); the latter consists of the shoot (8) with the coleoptile (7) and the root (9).

TABLE XII. CHEMICAL COMPOSITION OF DIFFERENT PARTS OF THE WHEAT KERNEL (Hegsted *et al.*, 1954)

	Entire kernel	Testa and hyaline layer	Endosperm		Embryo	Scutellum
			Outer	Inner		
Per cent of kernel	100	12	3	82·5	1	1·5
Thiamin, mg./100 gm.	0·4	0·48	0·45	0·06	0·9	16·5
Riboflavin, mg./100 gm.	0·15	0·5	0·18	0·07	0·15	1·5
Nicotinic acid, mg./100 gm.	4·2	25·0	18·0	0·5	6·0	6·0
Phosphorus, mg./100 gm.	311	1,650	1,020	60	1,160	1,900
Phytin phosphorus, mg./100 gm.	213	1,135	875	8	400	1,300
Iron, mg./100gm.	3	16·6	12	0·5	9	—

ENZYMES IN FLOUR

Flour is not an inert substance, but contains some active enzymes which act on proteins and starch. These enzymes play important roles in baking. In order to understand the various steps in the transformation of flour to bread it is necessary to know the nature of these enzymes and the role they play in the process.

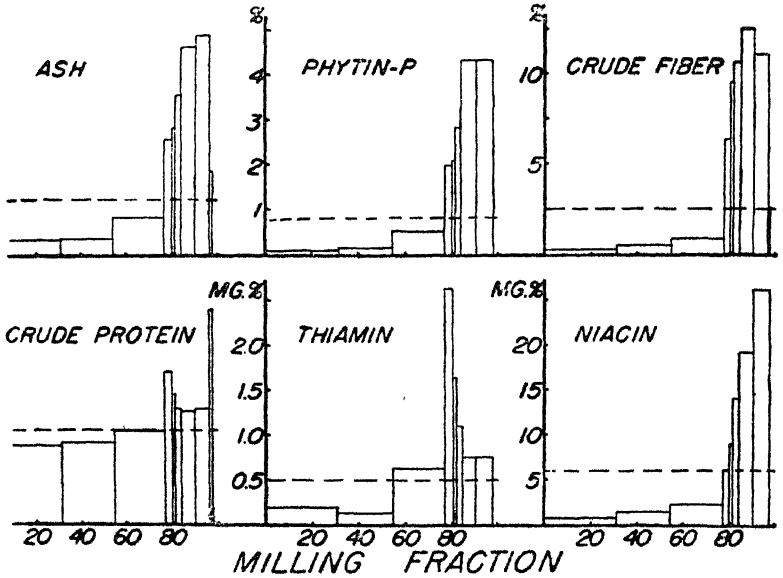


FIG. 9. Composition of various fractions separated during the milling process

(*After* Hegsted *et al.*, 1954)

TABLE XIII. COMPOSITION OF FLOURS OF DIFFERENT EXTRACTION (ENGLISH WHEAT)
(McCance *et al.*, 1945)

Extraction %	Crude protein %	Fibre %	Ca %	P %	Phytin P %	Fe mg. %	Thiamin mg. %	Niacin mg. %	Riboflavin mg. %
46	7·64	Trace	15·2	0·069	0·010	0·95	0·16	0·50	0·05
70	7·92	Trace	18·9	0·084	0·025	1·40	0·28	0·75	0·06
75	7·98	0·15	19·2	0·093	0·030	1·35	0·42	0·80	0·06
80	8·21	0·19	21·5	0·118	0·057	1·65	0·60	0·90	0·08
85	8·55	0·42	24·5	0·153	0·073	2·22	0·84	1·05	0·12
100	8·89	2·08	35·5	0·340	0·233	3·05	0·96	4·80	0·17

The most important enzymes in wheat are those which are collectively known as diastatic enzymes. They break down some of the starch into sugar, principally maltose. These enzymes occur chiefly in the embryo or germ of the wheat grain. All flours contain a certain amount of these enzymes.

Diastatic activity of different wheats, determined at Lyallpur (Anon., 1946, 1947) and recalculated on a uniform moisture basis of 13·5 per cent was reported to vary from 256 (Ao. 68) to 704 (C. 228 from Kala Shah Kaku). It has been observed in the past that ordinarily diastatic activity of Indian wheats varies from 150 to 300. Taking these as the normal values for Indian wheats, it may be pointed out that most of the samples tested at Lyallpur were either high or on the high side in diastatic activity. Diastatic activity of 31 Indian wheats, as reported by Rattan Singh and Bailey (1940), varied from 221 to 291, with an average of 256·7.

Thirty varieties of Indian wheat showed a variation in the maltose figure from 124·1 to 217·0 (Banerjee and Das, 1954). Maltose figure within the range from 150 to 230 in flour is desirable for the purpose of baking. Twenty-nine of the 30 wheats tested showed this range of maltose value. In the use of flours, with maltose value lower than 150, the dough may produce insufficient gas. If, on the other hand, the maltose value is much above 230 the crumb may be damp and sticky, and the loaf may show signs of collapse (Kent-Jones and Amos, 1959).

The gluten content has been found to be approximately proportional to the protein content; therefore, relationship of the diastatic activity to gluten or protein content appears to be the same (Banerjee and Das, 1954).

The small amount of maltose and cane sugar, originally present in flour, are first fermented by the yeast in the dough. As these sugars are used up in the initial fermentation process, the β-amylase present in the flour produces more maltose. The production of gas at the critical time of 'proving' is due to the action of yeast on this additional maltose formed by the β-amylase during the fermentation. The original sugars are used up by this time. A flour with a very small diastatic activity will not take very much colour on the crust when baked, so that the bread tends to have an anaemic appearance. Further, such a flour may not produce in the dough sufficient gas, resulting in the production of small and unsatisfactory loaf. A certain amount of diastatic activity in flour is, therefore, not only desirable but essential (Kent-Jones and Amos, 1959).

Wheat flour contains many enzymes other than diastatic enzymes. A fermenting dough made with yeast contains still more enzymes. The enzymes present in yeast are maltase, invertase and zymase. There are also proteolytic enzymes in the flour, which act on wheat proteins. The action of excessive proteolytic enzymes on gluten is usually harmful as the elastic properties are damaged and consequently the gas-retaining power is reduced. Some degree of proteolysis is, however, required in panary fermentation for the ripening of dough. Acid formed during the process of fermentation also possibly helps, but without some proteolysis the dough would be too unyielding and dead (Kent-Jones and Amos, 1959).

Besides the diastatic and proteolytic enzymes, wheaten flour also contains the enzyme phytase. Phytic acid, when ingested, seriously interferes with the absorption of dietary calcium and iron; hence, a high phytic acid content is undesirable in foodstuffs. The enzyme phytase, also present in flour, is capable of hydrolysing phytic acid into phosphoric acid and inositol. The adverse effect of a flour product upon calcium metabolism will depend not only upon its initial phytic acid content but also upon the extent to which this has been acted upon by phytase during the preparation of the food. Phytase has, thus, assumed importance because it has a marked influence upon the nutritive value of wheat and wheat products.

BAKING AND *CHAPATTEE*-MAKING QUALITY

Dough testing. The majority of tests for determining flour quality have been essentially chemical in nature or involve actual baking tests. In recent years, however, mechanical and physical tests have improved so much that they are now widely used. It would be very useful, if it were possible, to make accurate measurements of the physical characteristics of doughs and of the changes that these doughs undergo in the course of fermentation. The baking test largely depends upon the baker's assessment of the dough qualities. When a baker says that a flour is good or poor, he means that the flour, when made into dough, has certain physical qualities which he knows generally result in good or bad bread. Unfortunately, one baker's assessment of a particular dough may not be the same as that of another. If it were possible to measure dough qualities scientifically by an apparatus which is not influenced by the opinion or skill of an operator, a considerable step forward towards the solution of the various problems with respect to baking quality will have been taken.

A number of apparatuses have been developed to get an insight into the inherent qualities of wheats. More frequently used ones are the Brabender equipments, such as Farinograph, Extensograph, Amylograph, Fermentograph, etc. Besides, the Chopin Extensograph and other equipments are also in use. The usefulness of any particular equipment largely depends on the nature and scope of the problem to be tackled. Some of the apparatuses are described below.

Farinograph : This is used to assess the characteristics of wheats and wheat blends such as water-absorption capacity, strength of the wheat, dough development, stability and degree of softening, etc.

Extensograph : This is used for determining the flour quality by measuring factors like extensibility and resistance to extension of a dough under fermentation. The extensograph also gives information on any changes brought about by conditioning of the wheat or by treatment of the flours.

Fermentograph : It is a special instrument to measure the gassing power of wheat flours, and also the effect of various kinds of yeast and other stimulants.

***Chapattee*-making.** In this country wheat is consumed chiefly in the form of *chapattees* and to some extent in the form of bread and biscuits. Though the principles of bread-making are well studied, those of *chapattee*-making are yet little understood.

In bread-making, a mixture of flour, water, salt and yeast is allowed to ferment. The flour when mixed with water forms a complex dough having elastic properties. This behaviour is peculiar to wheat on account of the presence of gluten in it. With normal flours, the gluten absorbs about twice its weight of water and the starch takes up about 30 per cent of its weight of water. In general this accounts for about 80 per cent of the added water, the remaining 20 per cent is held in free state in the dough by capillary action. Because of its characteristic properties, the dough is able to hold the major part of the gas subsequently generated within it and, hence, is able to rise. Some flours may form doughs with physical properties, so far as bread making is concerned, more pleasing than those of others depending, of course, on the quantity and quality of the gluten present.

If the dough is kept warm, the yeast brings about fermentation, that is, it causes an evolution of gas. The yeast ferments the sugars existing in the flour into carbon dioxide and alcohol. The sugars which are present in the dough and which are ultimately fermented by yeast are maltose, dextrose, levosin and cane sugar. When these sugars are used up, further supply of sugar is made available by the diastatic enzymes of the flour which continuously produce maltose and other fermentable material after the dough is made.

The production of the gas, carbon dioxide, and alcohol from the sugars pre-existing in the flour and from those formed during fermentation is dependent upon the action of certain enzymes contained in the yeast. Therefore, throughout the fermentation period a series of changes take place which affect the colloidal state of the ingredients and the activities of the enzymes (Kent-Jones and Amos, 1959).

In order to satisfy a baker the flour must have a high capacity for water absorption and the dough must be of good elasticity and stability in order to yield a loaf of large volume with a golden-brown crust and good internal crumb structure and colour. These qualities of flour are, on the other hand, dependent upon the genetic make-up of the wheat, soil and climate.

Researches conducted in the U.S.A. show that for any one variety, the protein content alone accounts for about 90 per cent of the variation in loaf volume irrespective of soil, climate, season, etc., provided the proper improvers are used in baking (Teakle, 1952).

Farquhar reported good correlation between protein content and loaf volume when improvers such as malt, phosphate and bromate were used.

Teakle (1952) reported improvement in the volume of loaf prepared from wheat flour when the same wheat plants were sprayed with urea at the time of flowering.

Rattan Singh and Bailey (1940) performed the baking test on a few Punjab wheats. The average loaf volume is reported to be 502 cc. with a maximum of 615 cc. which is of the order of American soft winter wheats. The average is the result of a great variation in the loaf volume which is suggested to be due to the different genetic make-up of the wheats. Farinographs show that the dough-development times of those flours, with few exceptions, were short. The range of dough stability was also comparatively narrow.

Baking tests of Indian wheats were also done at the Agricultural College and Research Institute at Lyallpur, Punjab (Anon., 1946, 1947). The cumulative effect of all bread-quality points, such as type, texture, crust, crumb, grain and volume, were summed up into a single ' Quality Score '.

The water absorption of the Punjab wheats was found to vary from 76 to 80 per cent, though one wheat had 92 per cent. The water absorption of pure Manitoba wheat flour was less than that of its blend with Indian wheats while that of pure Indian wheat flour was higher than that of Manitoba-India wheat blend (Anon., 1946, 1947; Rattan Singh and Bailey, 1940).

The water-absorption capacity of 14 Indian wheats grown in triplicate at Delhi has been found to vary from 73 to 82 per cent (*Final Rep., I.A.R.I.*, 1957).

The effect of nitrogen application and the frequency of irrigation on the baking quality of two wheats was studied at Lyallpur. The application of nitrogen at 50 lb. per acre is reported to have shown perceptible effect in improving the baking quality.

Baking quality was also found to be high with one or two irrigations, though it was not significantly so (Anon., 1946, 1947).

A few Indian wheats were tested at Lyallpur for their *chapattee*-making quality. The water-absorption capacity, dough behaviour, and colour, taste and texture of *chapattees* were taken into consideration. Amongst the samples received from Niphad

(Maharashtra), Niphad-4, *Gulab* and 5–67 were reported to make good *chapattees* followed by *Motiya*; while of the Lyallpur-grown wheats A. 115 made all-round good *chapattees*, followed by Niphad-4 and Ao. 68 (Anon., 1946, 1947; Rattan Singh and Bailey, 1940).

Chapattee-making quality of 14 Indian wheats grown in triplicate at Delhi was adjudged organoleptically by a panel of six tasters on the basis of colour, sweetness, glutinous nature, flavour and behaviour on chewing.

For the sake of convenience an arbitrarily chosen reference variety, C. 591, was taken each time the test was performed. It was observed that amongst the varieties N.P. 4, 52, 125, 165, 710, 718, 737, 758, 760, 761, 770, 775 and K. 13, N.P. 770 and 775 scored somewhat better than the reference variety C. 591 while N.P. 52, 758, 760, 761 and K. 13 scored nearly as high as C. 591. N.P. 165, 710 and 737, however, were poor. No correlation existed between the *chapattee*-making quality score and the protein content of the variety (*Final Rep.*, *I.A.R.I.*, 1957).

A few Punjab wheats were also tested for their baking and *chapattee*-making quality (Rattan Singh and Bailey, 1940).

Losses in preparation. From the nutrition point of view the losses in vitamins, reduction in the nutritive value of proteins and the beneficial effect on calcium absorption as a result of the destruction of phytic acid during preparation and processing of wheat flour and their products are of considerable importance. Amongst the vitamins, thiamin is of most interest as it is very easily destroyed. It has been reported that the time for which bread or *chapattee* is exposed to heat is of more importance than the amount of surface exposed. Others have shown that pH is an important factor (Hegsted *et al.*, 1954).

Thiamin losses in cooked cereals have been studied by several groups of workers. In this country Ahmad *et al.* (1948) were among the first to study the loss of thiamin in the preparation of articles of food from wheat flour. The preparation of *chapattee* was found to involve a loss of 12·3 to 33·3 per cent. Higher thiamin-containing wheats lost a higher percentage of it. Other Indian preparations such as *roti*, *khamri*, *paratha*, *puri* and *kulcha* were also studied and the loss of thiamin was found to vary from 40 to 91 per cent in different preparations.

Similar work on the influence of cooking on the nutritive value of *chapattee*, bread and *puri* was reported by Pai (1954). Loss in thiamin was more marked in the case of bread and *puri*, while the loss in nicotinic acid was pronounced in the case of *puri*.

WHEAT BLENDS AND SUBSTITUTES

In view of the present shortage of food grains in this country, investigations have been carried out on the utilization of oilcakes and tuber flours as partial substitutes for cereals. A cheap and balanced food consisting chiefly of oilcakes, tuber flours and wheat flour was developed at the Indian Institute of Science, Bangalore (Lal and De, 1952; Lal and Rajagopalan, 1952, 1957). The processed food was found to be highly nutritious and two ounces of it were reported to be capable of meeting one-third of the daily requirements of proteins, vitamins and minerals of an adult (Lal, 1952). Grain substitutes of high nutritive value were at the same time prepared from a blend of tapioca, groundnut and wheat flours at the Central Food Technological Research Institute, Mysore, India (Subrahmanyan *et al.*, 1954, 1958d). Attempts to make *chapattee* and *puri* from such blends of wheat, tapioca and groundnut flour were also made. Certain blends, such as: (1) whole wheat flour 75 parts+tapioca flour 25 parts, (2) whole wheat flour 70 parts+tapioca flour 25 parts+groundnut flour 5 parts, and (3) whole wheat flour 85 parts+groundnut flour 15 parts, were reported to be quite suitable for making *chapattee* and *puri*. Organoleptic tests revealed that the *chapattee* and *puri* prepared thereby were equally acceptable as those prepared from wheat flour (Subrahmanyan *et al.*, 1958e).

Replacement of 25 parts of wheat flour by tapioca flour resulted in a reduction in the protein content of the blend. Incorporation of 5 parts of low-fat groundnut flour made up the deficiency of protein in tapioca flour. Admixture of low-fat groundnut flour at 15 per cent level with wheat flour, on the other hand, resulted in a marked increase in the protein content of the blend (Subrahmanyan *et al.*, 1958e).

Biscuits, fortified with calcium carbonate and vitamins A, B_1, B_2 and nicotinic acid, containing15 to 16 per cent protein, were prepared by replacing 40 per cent of the wheat flour in the biscuit mix by groundnut flour (Subrahmanyan *et al.*, 1958c). The effect of baking on the nutritive value of such biscuits was studied. Baking was found to have adversely affected the quality of protein in the biscuit (Subrahmanyan *et al.*, 1958b).

Extensive studies were also made at the Central Food Technological Research Institute, Mysore, to produce, on a large scale, a composite grain-like product from cereal substitutes. A mixture of tapioca flour 60 parts, groundnut flour 15 parts and wheat semolina 25 parts was found suitable for making tapioca macaroni in the form of rice-shaped grains, short tubes and shells in a pilot plant specially designed for the purpose (Subrahmanyan *et al.*, 1958a).

It was further reported that partial replacement of rice in the diet of children by tapioca macaroni did not cause any deterioration in the general health and nutritional status of the children (Subrahmanyan *et al.*, 1958f). It caused, on the other hand, an appreciable increase in the retention of nitrogen, calcium and phosphorus (Joseph *et al.*, 1958).

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IX

PHYSIOLOGY

As wheat is grown over a wide range of soil and climatic conditions in different parts of the world, it must necessarily have a wide adaptability and, as such, a proper understanding of the physiology of this adaptability should not only be of considerable scientific interest but also of obvious practical significance. Although considerable physiological research has been carried out in several important wheat-growing areas of the world, similar studies are essential in India because of some peculiar conditions under which wheat is grown in this country. It appears that fundamental aspects of the physiology of wheat have not received attention in keeping with the importance of the crop to this country. Some applied aspects, such as growth and yield in relation to drought, temperature, light and nutrition, have been investigated; the results of these investigations are discussed in relation to observations reported from other countries.

MOISTURE RELATIONS

In important wheat-growing countries, like the U.S.A., Canada, Australia, the U.S.S.R. and India, wheat is grown over large areas under semi-arid conditions; therefore, breeding of drought-resisting varieties has claimed considerable attention and effort. Although field experience under dry conditions has been usually relied upon for the assessment of drought resistance, it has been considered that knowledge of the fundamental basis of drought resistance might prove useful in breeding for this quality. Desert plants have naturally attracted particular attention in this connection on account of their obvious drought resistance. Xerophytic features, such as reduced leaf surface, diminution of intercellular spaces, sunken stomata, thickened cuticle, surface hairs and water-storage cells, are, however, regarded as of secondary importance compared with the capacity to endure without, or with the least, injury, an intense loss of water and the latter property of the cells alone is considered to indicate true drought resistance (*cf.* Maximov, 1929). This true drought resistance is also called desiccation resistance in current literature. Maximov (1929) further pointed out that desiccation resistance may completely mask the significance of xerophilous characters, and thus mystify investigators who endeavour to find a strict correlation between desiccation resistance and these external peculiarities. It has been considered that properties, such as osmotic concentration and bound water content of cell sap and protoplasmic viscosity, might give an indication of desiccation resistance; methods of determining desiccation resistance as such of tissues and whole plants have also been suggested; and finally, certain morphological characters have also been compared. A brief account of these and other related investigations is given below.

Investigations on osmotic concentration, bound water content and protoplasmic viscosity. Newton (1924) found the colloidal content of the cell fluids to vary directly with relative frost resistance of wheat varieties and pointed out a fundamental relationship between the physical nature of cold resistance and drought resistance. Newton and Martin (1930) determined the osmotic pressure, bound water content and imbibition pressure of leaf tissue of a number of varieties of wheat believed to vary in drought resistance. A few relevant data are given in Table XIV.

TABLE XIV. OSMOTIC PRESSURE AND BOUND WATER CONTENT OF SOME SPECIES OF *TRITICUM*

Species	Osmotic pressure (atm.)	Bound water (%)
Triticum dicoccum, Common emmer	12·0	7·2
T. durum var. Kubanka	13·8	7·0
T. turgidum var. Alaska	13·4	6·9
T. aestivum var. *caesium*	14·2	6·5
T. compactum var. Hybrid 143	13·0	5·8
T. spelta var. White spelt	14·7	5·6
T. monococcum, Einkorn	12·6	5·6
T. polonicum var. White Polish	12·4	4·4
T. aestivum var. Marquis	13·5	4·1

It is evident from Table XIV that bound water content alone was correlated with the drought resistance of the different wheats. Calvert (1935) also arrived at a similar conclusion. But Newton and Martin (1930) drew the same conclusion guardedly. They pointed out that " the classification is logical so far as can be judged from common knowledge and experience...... A logical development of these experiments would be to grow the varieties under a series of controlled moisture conditions, from the optimum to minimum and observe the effect on growth, yield and juice properties. " It may further be noted that Whitman (1941) did not find any correlation between bound water content and drought resistance of grasses, a result in contradiction with Newton and Martin's observations. According to Levitt (1956) also the methods of determining bound water content of plant tissues are not foolproof. He suggests that increase in colloidally bound water in the protoplasm alone may be expected to give a correct idea and as such determinations on whole pieces of tissues, which are more than 90 per cent non-protoplasmic, should be avoided.

We have seen that Newton and Martin (1930) did not find any correlation between drought resistance and osmotic pressure. Bartel (1947) compared the leaf water content and osmotic pressure and total solids of four varieties of wheat, Baart, Ceres, Marquis and Hope, under irrigated and unirrigated conditions. The reduction of leaf water content under deficient soil moisture was found to be approximately the same for the varieties; the increase in osmotic pressure and total solids was the greatest in Baart and the least in Hope, thus showing some correlation with the supposed drought resistance of the varieties, Baart being relatively more drought resistant than Hope. In view of these conflicting results, it would appear that osmotic pressure and cell-sap concentration, though related to drought resistance, are not always the deciding factors.

Schmidt *et al.* (1940) claimed that drought-resistant varieties of oats had greater viscosity of protoplasm than susceptible varieties and that it could be determined in the coleoptile. Levitt (1956) has, however, pointed out on theoretical grounds that protoplasmic viscosity in relation to drought has not been reliably determined so far.

Desiccation-resistance tests on tissues. Whiteside (1940) has described a method for studying the desiccation resistance of cells of leaf sheaths of wheat. Sections of leaf sheath were exposed to solutions of different molar concentrations of sodium chloride which served as the desiccating agent. The percentage of cells surviving (as indicated by staining with neutral red) was taken as a measure of desiccation resistance. In the desiccation tests, varietal differences were indicated for plants ' hardened ' both by soil drought and by low temperature, and in these tests the varieties arranged themselves in a similar manner irrespective of the method of hardening used. According to Whiteside, desiccation tests would not be feasible for segregating populations but may be of service in the selection of parental varieties or in obtaining information on promising selections. He also points out that as it is useless to test ' unhardened ' plants, the difficulty of control of hardening by soil drought limits the utility of this test, and " the final test for any wheat variety for areas subjected to limited moisture supply will be found in whether it has the ability to yield adequate returns under relatively dry conditions over a period of years ". Milthorpe (1950) also attempted a modified form of desiccation test. He exposed seedlings of a drought-resistant and a drought-susceptible wheat (known from field experience) to dry air over sulphuric acid and found that both types of seedlings were completely resistant from the dormant embryo stage until the coleoptile was about 4 mm. long. The proportion of meristematic to elongated cells decreased with age and the meristematic cells were highly resistant to desiccation.

Desiccation-resistance tests on whole plants. For these tests plants grown in pots were subjected, at various growth stages, to soil drought (withholding water until permanent wilting) and/or atmospheric drought (hot dry wind in a chamber) and the relative injury and/or survival on return to normal conditions were assessed. Some important results are summarized in Table XV. It will be seen that these tests do not give a consistent indication of varietal difference in drought resistance.

Some variants of desiccation tests. Mackov (1936) dipped leaves or whole plants in water at 50° to 60°C and noted the colour. He claimed that varietal differences appeared very clearly and that this technique could be used as a rapid test for heat or drought resistance. Stefanovoskii (1937) immersed plants (dug-out) in hot water at 46° to 50°C for 10 to 20 minutes at: (i) the beginning of the ear-sheath stage, (ii) the ear emergence, and (iii) the milk-ripe stage. Recovery after ten days, on replanting, was recorded and varietal differences were particularly noticed at stage (iii). He also studied a number of varieties in the same way as above but omitted the hot-water treatment, and found that certain varieties were more resistant to drying at all

TABLE XV. SUMMARY OF RESULTS ON DESICCATION TESTS OF WHOLE PLANTS

Worker	Observations
	Soil drought
Tumanov (1927)	Survival rate of varieties in agreement with general field experience.
Papadakis (1933)	General agreement between pot test and field experience.
Platt and Darroch (1942)	Low correlation value between survival and yield under field conditions.
	Atmospheric drought
Aamodt and Johnston (1936)	Fair agreement, with some exceptions, between injury and field experience at early shooting stage but little agreement at soft or hard dough stage.
Bayles *et al.* (1937)	Good agreement between test data and field experience.
Stefanovoskii (1940)	Fair correspondence, with some exceptions, between test data and field experience.
Kenway *et al.* (1942)	No clear relation between test data and yield under field conditions.
Birdsall and Neatby (1944)	No relation between test data and yield under field conditions.

stages. It is suggested that this method, in combination with field experiments, would be useful for testing drought resistance. Bayles *et al.* (1937) compared the water loss at room temperature from shoots (without roots) of eight varieties. The lower rate of water loss of some varieties corresponded with their known resistance to drought under field conditions. When the varieties were grown at two different locations, the order of varieties in respect of water loss did not correspond closely. It may be concluded that this test also does not give a consistent index of drought resistance and is not practicable for large-scale work when it involves digging out of plants.

Morphological characters. Cell size and root development have received considerable attention. Kolkunov (1905) was perhaps the first to indicate the importance of small cell size in relation to drought resistance. He concluded that with abundant water the best yields were obtained from wheats with larger stomata and under dry conditions from those with smaller stomata while with average conditions the wheat with stomata of an intermediate length gave the best results. Although the physiological interpretation given by Kolkunov for this correlation has been criticized by Maximov (1929), the latter accepts the significance of this correlation. It may be noted that Kolkunov found that small stomata were associated with small epidermal and mesophyll cells in the leaf and with small parenchymatous cells in the root; as such stomatal size, because of convenience of observation, was taken as an index of cell size. Vasiliev (1929) did not, however, find any relation between stomatal length and cell size, while Pavlov (1931) observed that in general smaller stomata were characteristic of more drought-resistant and early varieties of winter wheat, but not of spring wheat. Birdsall and Neatby (1944) found that yield of wheat varieties and crosses was positively correlated with stomatal frequency and negatively with stomatal size. Results of replicated field trials, conducted over a three-year period, were used as a measure of drought resistance and stomatal data were obtained from tests that were independent of those from which yield results were obtained. The authors consider further work necessary to establish this relationship.

It may also be mentioned that the authors make no mention of the degree of drought prevalent during the three seasons, over which yield was taken as a measure of drought resistance. Birdsall and Neatby further suggested that in view of the negative correlation of yield with stomatal length as well as protein content, the positive correlation between protein content and stomatal length can be used in selecting for yield and drought resistance. According to them, stomatal length on seedling leaves may prove useful in selection in view of a higher correlation between stomatal length and yield and protein content, when seedling leaf determinations were used than when terminal leaves were used.

Ivanov (1939) found considerable variation in the rate of root growth. One variety had a very short root system during tillering and ear emergence; but, subsequently, while the roots grew vigorously the foliage grew slowly, and the drought resistance of such a variety during the second half of the vegetative period and its poor productivity were attributed to this behaviour. Another variety had a short root system up to tillering, but during the next two developmental stages the roots as well as foliage grew rapidly; this variety was both highly drought-resistant and productive. Aamodt and Johnston (1936), Hubbard (1938), and Birdsall and Neatby (1944) also found varietal differences in the root system of wheat. The last two authors, however, conclude that no clear relations between varietal differences in root system and yield under field conditions were established and the tests were as expensive and time-consuming as regular yield trials.

Seed-germination test. It has been suggested that an indication of drought resistance may be obtained from the rate of germination of seeds in sugar or salt solutions. While Bolsunov (1927), Pavlov (1931), Bachinger (1936), Timofeeva (1933) and Semakin (1938) observed this relation to hold good, Skazkin (1934), Aamodt and Johnston (1936), and Birdsall and Neatby (1944) did not find evidence to justify this conclusion.

A variant of this method has been described by Powell and Pfeifer (1956). These authors argued that for the establishment of good vigorous autumn stand of winter wheats, germination and early growth may be critically dependent upon limited soil moisture; therefore, development of selections with greater ability to establish stands would be a definite contribution to the production of winter wheat. They designated this property as *seedling drought hardiness.*

Seeds of 670 single-plant selections from Cheyenne winter wheat were germinated in solutions of mannitol (soaked in filter paper) with osmotic pressures of 7 and 11 atmospheres for nine days and the epicotyl lengths were measured. Remnant seed of the 670 S_0 selections was planted and was advanced one generation. Seeds of 34 selections (which were the same pedigree selections as classified in high and low groups in the S_0 test) from S_1 generation were retested. A correlation of $+0 \cdot 72$ between S_0 and S_1 generations was found in the growth made by each of the 34 selections retested. It is suggested that this technique should prove useful in selecting for seedling drought resistance. It may, however, be pointed out that no yield comparisons are given and it is assumed that such selections would perform better.

Water requirement. It was expected that the amount of water required to produce a gram of dry substance may serve as a useful index of drought resistance; this expectation has not generally been fulfilled and even if varietal differences have been noticed, they were too small to be useful for purposes of selection (Tulaikov, 1922; Richardson, 1923; Dillman, 1931).

Work on drought resistance at the Indian Agricultural Research Institute. The wheat season extends from about the middle of October to middle of April in North India and is shorter by about a month in the rest of the wheat-growing tracts. Besides scanty rainfall during this period, wheat is largely grown under unirrigated conditions. Pal (1944) recognized, therefore, the importance of breeding drought-resistant wheats at the Indian Agricultural Research Institute and, as a first step, physiological investigations were conducted during 1940 to 1947 by Chinoy (1947a, b).

Chinoy made a study of about 260 varieties of exotic and Indian wheats grown under dry and irrigated conditions. The Indian varieties were representative of the important wheat-growing tracts of the country and the exotic ones of the important wheat belts of Canada, U.S.A., U.S.S.R., Great Britain, Australia and other countries. All these varieties formed a part of the wheat collection maintained at this Institute.

The vegetative period of these varieties (time from sowing to ear emergence) ranged from about 90 to 170 days and Chinoy (1947a, b) grouped these varieties under eight classes with a class interval of ten days. The values of grain yield, ripening period, 1,000-grain weight and ear/tiller ratio were averaged from the corresponding values for all varieties falling within a class. There was noticed a progressive fall in grain yield and 1,000-kernel weight from the early- to late-flowering varieties. The grain of late varieties ripened more quickly than that of the early varieties. Ear number per plant did not increase in late varieties in spite of heavy tillering and, as such, ear/tiller ratio declined with lateness in flowering. Mean maximum and minimum temperatures and mean per cent relative humidity for each variety were calculated by summing up all the values of the respective climatic factor during the ripening period and dividing by the number of days of the ripening period. Total and partial correlation coefficients, showing relationship between grain yield (a), 1,000-kernel weight (b), and mean maximum temperature during the ripening period (c) were calculated (Table XVI).

The correlation coefficients showed the same trend under dry as well as irrigated conditions; thus, indicating that there was a more pronounced effect of atmospheric drought at least during the ripening period and that even if the level of moisture in the soil was raised by a late irrigation, its effect on yield was smaller than that of the adverse climatic factors, namely, the temperature prevailing during the ripening period. This was further supported by the comparison of indices of resistance to soil and atmospheric drought which are presented in Table XVII.

The index of resistance to soil drought was calculated by dividing the yield of a variety grown on dry land by the yield of the same variety grown on irrigated land in the same year and in the same locality. This index did not show any significant difference in different flowering classes. The index of resistance to atmospheric drought, which was obtained by dividing individual yields of varieties in each class by the mean yield of the earliest class, on the other hand, showed a progressive decline with lateness in flowering. Thus, Chinoy's (1947a, b) work provided an experimental

TABLE XVI. TOTAL AND PARTIAL CORRELATION COEFFICIENTS BETWEEN GRAIN YIELD (a), 1,000-KERNEL WEIGHT (b) AND MEAN MAXIMUM TEMPERATURE DURING THE RIPENING PERIOD (c) UNDER IRRIGATED AND UNIRRIGATED CONDITIONS (Chinoy, 1947a)

Total correlation coefficient		Partial correlation coefficient		Observed value of 't'
		Irrigated		
r_{ac}	−0·83 to −0·70	$r_{ac.b}$	−0·60 to −0·27	39–7 S
r_{ab}	0·87 to 0·68	$r_{ab.c}$	0·58 to 0·56	87–19 S
r_{bc}	−0·83 to −0·44	$r_{bc.a}$	−0·47 to −0·07n	26–0·6 S
		Dry		
r_{ac}	−0·81 to −0·66	$r_{ac.b}$	−0·51 to −0·15s	32– 2 S
r_{ab}	0·88 to 0·64	$r_{ab.c}$	0·60 to 0·45	38·10 S
r_{bc}	−0·89 to −0·54	$r_{bc.a}$	−0·62 to −0·18	40– 3 S

n, not significant; s, significant at 5 per cent; S, significant at 1 per cent.

TABLE XVII. RESISTANCE INDICES (Chinoy, 1947a)

Index of resistance to	Vegetative period (days)							
	100	110	120	130	140	150	160	170
Soil drought	0·56	0·45	0·60	0·56	0·47	0·45	0·47	0·53
Atmospheric drought	1·00	0·94	0·94	0·75	0·67	0·48	0·39	0·16

confirmation of the observation made by Howard (1924) that in India early wheats yielded better than late ones by virtue of their capacity to avoid high temperatures.

Resistance to wilting: Chinoy (1947a, b) also studied the response of a number of varieties of wheat to rewatering, after permanent wilting over a number of days, at various growth stages. All the varieties showed considerable resistance to drought at the tillering stage by recovering completely and giving a slightly higher yield of grain than the control (normal watering). On the other hand, wilting during the shooting and flowering stages reduced growth and yield considerably.

Hardening to drought: Chinoy (1947a, b) also tried the effect of alternate soaking and drying of seeds on yield under field conditions and obtained an average yield of 948 lb. per acre from the treated seed as against 866 lb. from untreated seeds on dry land over a period of three years. No further results have been reported in this connection.

After Chinoy's departure from the Indian Agricultural Research Institute, Asana and his associates took up investigations on this subject on early and early-medium varieties using pot as well as field culture. In view of the general experience of other workers that desiccation and other *ad hoc* tests and xerophilous characters had not pointed to any consistent index of drought resistance, Asana approached the problem from a slightly different angle. He (1957) has discussed this question elsewhere and has pointed out that " in view of the complex effects of drought on growth and development, it may perhaps prove more profitable in the first instance to examine the effect of drought on characters directly related to yield ". He compared the relation of the three important characters, namely, ear number, grain number per ear and 1,000-grain weight, with yield under normal water supply and under deficient moisture. For the drought treatment, the pots were watered only when the plants wilted permanently and did not recover in the early morning. Thus, the ' drought' plants were subjected to soil moisture ranging from ' field capacity ' to ' wilting coefficient '; at no time were the plants subjected to permanent wilting for long. This technique ensured that the plant was exposed to drought, i.e., to a high soil-moisture tension, and the ability of the plant to function under such a condition was, thus, tested. It was considered that an annual crop plant under field conditions was usually subjected to increasing soil moisture tension rather than to permanent wilting; thus, the technique of intermittent drought provided more natural conditions. The effects of drought from about three weeks after sowing to maturity and during other growth stages were studied under pot culture. In field experiments the effects of irrigation and omission of irrigation were compared and soil moisture was periodically determined up to a depth of three feet in order to ascertain the degree of drought experienced by the crop.

The variation in soil moisture, as it generally obtains in the non-irrigated wheat crop, may be briefly considered. The crop largely depends for its growth on the moisture stored in the soil during the previous rainy season and generally grows during its ontogeny on a decreasing soil moisture status (Fig. 10). The available soil moisture will also partly depend upon the winter rainfall (about two inches on an average) and in case of shortage the soil moisture in the upper layer might approach the level of the ' wilting coefficient ', more particularly from the earing stage onward (i.e., from February onward) as evidenced by the partial inward rolling of the leaf margins. Generally speaking, therefore, soil moisture stress would be experienced by the early and early-medium varieties during the period of grain development.

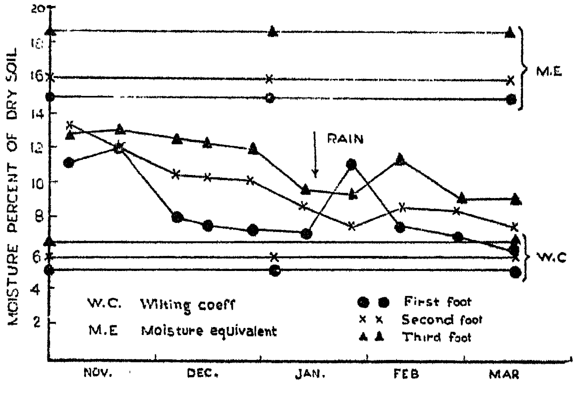

FIG. 10. Soil moisture status during the growth period of a wheat crop grown under rainfed conditions

Asana *et al.* (1955b), and Asana and Mani (1958) assessed the relation between yield and the three ear characters by calculating the standard partial regression coefficients

(β values of Snedecor), which give an estimate of the relative effect of each character on yield. The main results are summarized in Table XVIII.

TABLE XVIII. RELATIVE POTENCIES OF VARIOUS EAR CHARACTERS IN DETERMINING GRAIN YIELD UNDER NORMAL WATER SUPPLY AND UNDER DROUGHT CONDITIONS

		Relative potencies of characters	
Number of varieties	Season	Normal water supply	Drought
		Pot culture	
8	1947–48	E>G=H	E=G=H (Continuous)
11	1948–49	E>G>H	E>G=H ,,
7	1949–50	E>G>H	G>E>H ,,
7	,,		E>G>H (From anthesis)
7			G>H=E (From February)
15	1950–51	E>G>H	E=G>H (Continuous)
15	,,		E=G>H (From February)
		Field	
10	1948–49	E>G=H	E=G=H (Pusa)
10	,,	E>G=H	H=E=G (Delhi)
9	,,	E>G=H	E>G>H (Karnal)
15	1951–52	E>G=H	E=G>H (Delhi)

E=ear number per plant; G=grain number per ear; H=1,000-grain weight.

It is seen that under normal water supply, ear number had the dominant influence on yield; whereas, under drought, grain number per ear, and sometimes 1,000-grain weight, were as effective as ear number. For selecting varieties for non-irrigated conditions stress should, therefore, be laid on grain number per ear and 1,000-grain weight. It would seem unnecessary to grow plants under deficient water supply for selecting for these characters because varietal differences in respect of these remained more or less constant under these two conditions of water supply. Although there appeared to be a negative association, in general, between time of flowering and ear number, between grain number and 1,000-grain weight, and between grain number and ear number, exceptions were noticed in some varieties and as such it would not seem impossible to combine early flowering with reasonably high values of the three ear characters.

INFLUENCE OF LIGHT AND TEMPERATURE ON WHEAT

According to Klages (1942) there are 12, more or less distinct, wheat-producing areas in the world. These are: (1) the northern Great Plains of North America, (2) the southern Great Plains area of the United States, (3) the Columbia River

Basin and Palouse area of the United States, (4) north-western Europe, (5) the Mediterranean area of Europe and North Africa, (6) the Hungarian Plains, (7) the Danube Basin, (8) southern Russia, (9) north-western India, (10) east-central China, (11) Argentina, and (12) southern Australia. Generally speaking, the most extensive wheat-growing areas have continental grassland climate, although wheat production is by no means limited to this climate.

The wide adaptability of the wheat plant is due to the wide variation in its growth habit. In general, two main growth habits, namely, winter and spring, have been recognized, although in the ultimate analysis this distinction is not so very rigid. Winter wheats when sown at the normal time in autumn (October), in temperate climates, complete their life-cycle within a year, thus, behaving as annuals; if sown in spring, however, they behave as biennials, growing vegetatively in the first season and earing only after winter. Spring wheats, on the other hand, ear within a few weeks of spring sowing. It appears that winter forms are dependent for the completion of their life-cycle on the influence of some factors connected with autumn sowing, such as temperature and day-length, whereas the spring forms are independent of these. Spring forms replace winter forms where winters are intensely cold and unaccompanied by protective snow cover. Wheat can be grown under rather high temperature conditions provided high humidity does not prevail simultaneously. It is this combination that sets the northern limits of wheat production in Argentina, the eastern boundary of the wheat belt in India and the extension of wheat into southern China.

Over three-quarters of the world wheat crop consists of winter wheat. In general, with favourable conditions, higher and more stable yields can be expected from autumn-sown than from spring-sown wheat. Spring wheat requires a growing season of at least 100 days, but some wheat is also grown in areas with a shorter growing season and in such regions the crop is subject to a considerable frost hazard prior to maturity; in these same areas, late spring frosts corresponding with the flowering and early stages of grain development act adversely on the production of winter wheat.

Under conditions obtaining in the plains of India, wheat is sown in autumn (according to the terminology of temperate climates, the actual period being October-November) and harvested in spring. Thus, the duration is equivalent to that of spring wheat, whereas the trend in temperature and day-length to which the crop is exposed approximates to that of winter wheat in temperate climate, although the levels of these two factors are of a different order. It is no wonder then that the exotic varieties of wheat, particularly of more northern latitudes, do not fit in with Indian conditions.

The profound effect of temperature and day-length on the production of wheat has been sufficiently illustrated above and the importance of properly understanding its scientific basis cannot be too strongly stressed. Results of important investigations in this connection are reviewed below.

According to McKinney and Sando (1933), Klippart knew before 1857 that low temperatures applied to germinated seed induced winter wheat, when sown in spring, to mature and produce a good crop. Later, Gassner (1918) showed that summer wheat was practically independent of any need to pass through a cold period before it could achieve shooting, whereas the shooting of winter wheat depended on passing through a cold period either during germination or at some stage subsequent to germination. Maximov and others in the Soviet Union and other investigators elsewhere (Forster *et al.*, 1932; McKinney and Sando, 1930, 1933, 1935; Wanser, 1922) subsequently continued the experiments of Gassner. The main conclusions are outlined below.

Winter wheat can be induced to ear earlier by subjecting the plant to a short day and a low temperature during the early stages of growth and a long day and a high temperature during the later stages of development.

Slow germination with restricted moisture, at a temperature slightly above freezing over a number of weeks or a short day with low temperature in the early stages, followed by a long day and a high temperature can also hasten earing in winter wheat.

Darkness and light during the low-temperature-germination treatment had no differential effect on the time of heading of the plants from these seeds.

Temperatures and photoperiods favouring earliness in the winter and spring wheats bring about a reduction in the number of internodes, leaves and tillers.

The formation of the stem internodes and leaves stops and the major elongation of the stem begins at about the time the floral differentiation becomes evident.

Grain number is also reduced when winter wheat is forced to complete its life-cycle too rapidly. Seed yields are, however, higher when forcing is less rapid and is accomplished by means of low growing temperatures with short days, followed by higher temperatures and long days than is the case when the seeds are germinated at a temperature slightly above freezing with restricted moisture and the plants kept under high temperatures and long days.

Generally speaking, earliness of sexual reproduction depends upon: (1) the characteristic number of obligate leaf primordia and attending internodes; (2) the characteristics of the embryo which bring into existence or activate substances which in turn activate the labile lateral primordia into spikelets at characteristic (a) temperature, (b) photoperiod, and (c) periods of time; (3) the growth characteristics of the stem internodes; and (4) the rate of maturity of sex organs and seeds (McKinney, 1940).

The main conclusions of Dolgusin and Lysenko (1929; *fide* Whyte, 1946) may be appropriately considered at this stage.

Sowing date experiments indicated no definite dates dividing winter forms from spring forms. High temperature subsequent to sowing was one of the main factors preventing 'shooting'. But a pre-sowing chilling of slightly sprouted or swollen seeds at about 3°C for a definite period induced shooting in winter wheats when sown at any time. The duration of the second phase (shooting) was inversely related to temperature.

Thus, the retardation of shooting in plants sown without pre-treatment and exposed to a high temperature after sowing was due to prolongation of the unrecognizable phase; if the temperature of the period after sowing reached a maximum at and beyond which this phase for a given variety cannot be passed, then this variety will behave as a winter form and will not ear.

Since the temperature rises with the approach of summer, it was observed that the later the sowing the greater was the number of varieties which changed from spring to winter habit.

VERNALIZATION

In 1931–32 Lysenko issued instructions for the seed treatment, referred to in the earlier pages, which came to be known as vernalization. Lysenko also formulated certain theoretical principles which are enumerated below:

(a) growth and development are not identical phenomena;
(b) the entire process of the development of an annual seed plant consists of individual stages;
(c) the stages always occur in a strict sequence and a subsequent stage cannot commence until the preceding stage has been completed; and
(d) the different stages of development of the same plant require different environmental conditions for their completion.

According to Lysenko, growth means accumulation of dry matter or increase in size, whereas development signifies progress through stages of development. Vernalization reduces rate of growth and enhances that of development under the influence of the optimal temperature, i.e., low temperature. Without going further into Lysenko's theory of phasic development, it may be noted that several other investigators hold that low temperature is not obligatory for reproduction and short day can possibly be as effective (*cf.* Vasiliev, 1934; Lojkin, 1936; Voss, 1938; McKinney and Sando, 1933, 1935).

The other effects of vernalization are now briefly enumerated. According to Cholodony (1936), the embryo is activated by vernalization but cannot grow further because of insufficient moisture and low temperature; it, however, continues to absorb the growth hormones stored in the endosperm and their concentration in the embryo increases considerably because of lack of growth; the first phases of development are thereby accelerated and the life-cycle is shortened. This theory is, however, no longer considered valid.

Vernalization reduces the frost hardiness of winter wheats (Tumanov, 1940). It also induces changes in the protein substances of the wheat-germ affecting both their colloidal state and amino acid content (Pasevic, 1940).

The synthesizing capacity of vernalized wheat is increased not as a result of increase in the intensity of photosynthesis but due to hastening of the successive emergence of leaves. Each leaf, thus, attains its maximal size and releases food material sooner for the developing ear (Konovalov, 1944). Konovalov (1944) also found that vernalization increased the yield of late-maturing wheat, in spite of reduction in ear number, by increasing the number of spikelets and grains and weight of the grain; the yield of the early-maturing wheats was, however, not increased because the better development of ears could not compensate for decrease in ear number.

According to Zaiceva (1939) the chlorophyll content of leaves also increases.

While the grain ripens on the mother plant, it can undergo vernalization under appropriate conditions (Kostjucenko and Zarubailo, 1935). This finding has a particular bearing on the understanding of the unexpected behaviour of a plant introduced from another country with different climatic conditions.

Vernalization is effected more slowly in closed than in open jars, but the free access of air is necessary, not so much for increasing the oxygen content as for reducing the accumulation of respiratory carbon dioxide (Eremenko, 1936).

Devernalization of seeds of winter wheat, vernalized at 0° to 2°C for 40 to 45 days, could be brought about by an exposure to high temperatures (27° to 33°C) for six days (Efeikin, 1939). Vernalized seeds of winter wheat, dried for four weeks at 1° and 15°C, could be partially or completely devernalized (Lojkin, 1936).

Investigations in India. Kar (1940, 1942–43), Pal and Murty (1941), and Sen and Chakravarti (1945) found that cultivated strains of wheat, in general, did not respond to vernalization because of their short life-cycle. Kar (1940), and Pal and Murty (1941), however, observed that long photoperiod hastened earing in Indian wheats and the latter authors further noted that low temperature was necessary for the normal growth and yield of Indian wheats, because in summer, on account of long day (and also high temperature), earing was considerably hastened, the size of the ear was considerably reduced and tillering was almost completely suppressed.

In the case of English wheats, grown at Delhi, low temperature at the time of germination and a long photoperiod subsequently were found necessary for normal development (Pal and Murty, 1941); vernalization was also found to be necessary by Sen and Chakravarti (1945) for exotic wheats, such as Holdfast, Little Joss, Yeoman, Juliana and Yorkwin. It was also found that several late varieties from north-west India responded to vernalization.

Chinoy and Nanda (1946) observed that after the completion of the photophase, long as well as short day increased pollen sterility and that branching of the ear as well as compounding of spikelets was induced by transferring the plants from long to normal or short day.

Asana (1950) compared the natural day-lengths obtaining in the different wheat-growing tracts of India. His findings are given in Table XIX.

TABLE XIX. NATURAL DAY-LENGTHS OBTAINING IN THE DIFFERENT WHEAT-GROWING TRACTS OF INDIA

Latitude	Natural day-length (in hours, minutes)				
	November	December	January	February	March
32°N	10,23	9,51	10,20	11,07	11,51
30°N	10,42	10,16	10,24	11,13	11,54
28°N	10,42	10,16	10,24	11,13	11,54
24°N	10,58	10,37	10,44	11,17	11,59
20°N	11,13	10,57	11,20	11,28	11,58
16°N	11,17	11,15	11,19	11,38	12,00

In view of the fact that wheat yields, in general, decreased with the decrease in latitude and that there was a comparatively much wider variation in temperature (temperature increasing with decrease in latitude) than in day-length with latitude, temperature probably had a much greater influence on growth and yield. It was suggested that varieties evolved in farther northern latitudes would perhaps prove more adapted to southern tracts if they were further selected under high temperature conditions. Since maintenance of high temperature does not require any elaborate equipment, it would be possible to implement this suggestion where a glass-house with electric power is available.

On the basis of Pal and Murty's observation that Indian wheats eared even during summer at Delhi, Asana (unpublished) attempted to raise two extra generations of wheat, under the prevailing weather conditions, in order to expedite the breeding programme. It was observed that growth (under pots) was better from July onwards than during April-June because of milder weather conditions. Earing generally occurred about six weeks after sowing. In order to save time, ears were cut off about a week after dehiscence and dried off at room temperature. The much-shrivelled grains, however, germinated satisfactorily. It was, thus, possible to raise two generations during July to October. Unfortunately, the plants were attacked by the stem-borer fly, the grub of which destroyed the growing point of the main shoot. Although the main shoot died, growth of tillers continued but as the harvest of the main shoot was the main concern, the pest seriously jeopardized the success of the method. No control measures were readily available due to the fact that this pest did not attack the normally sown crop and, as such, further exploitation of this technique had to be abandoned.

Chinoy and Nanda (1951a, b, c) have described the results of a detailed analysis of the effects of temperature and photoperiod on growth, development and nutrition of wheat. Germinated seeds of the varieties N.P. 165, N.P. 52 and Pb.C. 591 were subjected to photoperiods, ranging from 0 to 24 hours for about two weeks (photo-inductive treatments); subsequently, these seedlings were exposed to photoperiods ranging from 6 to 24 hours.

The vegetative period (from sowing to anthesis) was markedly shortened by increasing photoperiod, the effect being seen even in the case of photo-inductive treatments which were given for a few days only. The rate of stem elongation was also accelerated by a long photoperiod in the initial stages with the result that the final height was attained earlier. Under normal as well as short days, the stem elongated more slowly and the period of elongation was more prolonged. In view of the positive correlation between the vegetative period and the duration of stem elongation it was inferred that the effect of the photoperiod on stem elongation was exerted through its primary effect on flowering. The earlier photo-inductive treatments had, on the whole, a smaller effect on stem elongation. Photo-inductive and varietal effects on tillering were also of a smaller order.

Dry weights of different plant parts of variety N.P. 52 under different treatments were also determined. The relative growth rate and the net assimilation rate were not influenced by different photo-inductive treatments. Under normal as well as long day they were appreciably accelerated. When the net assimilation rate was corrected for the hours of illumination the effect of long day disappeared; thus indicating that the decrease in dry weight as well as tillering was due to reduction in the duration of photosynthesis. Under long days the water content decreased more rapidly and the stem/leaf ratio increased earlier. The rates of uptake of nitrogen and potassium were higher under normal day, whereas that of phosphorus was greater under long day. The rates of uptake of the three nutrients were the slowest under short day. It would appear that the course of absorption of nutrients was determined more or less by the pattern of growth imposed by photoperiod.

Chinoy (1956) has suggested that the energy requirements of long-day plants (wheat, in his case) can be estimated from what he calls *photothermic* and *vernalization* *quanta*. Total number of light hours and the sum of degrees of mean diurnal temperatures during the vegetative period (number of days from germination or transplantation to anthesis) were designated, respectively, as *photo quantum* (P) and *thermic quantum* (T). The product of these two quantities (PT) was called the *photothermic quantum* (E) of a variety.

The photo quantum of a variety being a product of the mean diurnal photoperiod (p) and the vegetative period (F), and the thermic quantum a product of the mean daily temperature (t) and the vegetative period, it follows that

$$E = PT = ptF^2;\ \text{hence, } F = \sqrt{E/pt}$$

Chinoy (1956) suggested that if the photothermic quantum of a variety were known, the approximate time of ear emergence in any environment could be worked out from the above formula by finding out the mean day-length and mean daily temperature during the growing season; Chinoy (1956), however, added a proviso that " the vernalization quantum of a variety will have to be taken into account also ".

Vernalization in agronomic practice. Vernalization was recommended as an agronomic practice in Russia with a view to ensuring reliable crops in regions in which the growing period was short owing to frost or drought, or to ensuring the production of two crops per season on the same land. From 1932 to 1937 the area sown with vernalized seeds was reported to have increased from 43,000 to 10,000,000 acres (Whyte, 1946). It appears that in later years this practice has not been widely used. Trials to compare yields from vernalized and non-vernalized seeds, carried out in several other parts of the world, do not point to any substantial increase in yield in favour of vernalization. As a number of suitable spring varieties of wheat are available for use, it has not been considered desirable to sow vernalized seed of winter varieties.

The observation that vernalization has not found general use in agronomic practice does not belittle its value as a discovery of fundamental scientific interest. Lang (1952) has very aptly stated that " the significance of the study of the two phenomena (vernalization and photoperiodism) lies in the fact that they are toeholds for penetrating into the general physiology of floral initiation ". Apart from their scientific interest, vernalization and photoperiodism have provided very useful tools to plant breeders for synchronising, for crossing purposes, the flowering of two varieties which, under normal environmental conditions, flower at widely different times.

GROWTH AND NUTRITION

A number of workers in different parts of the world have studied the growth (increase in dry matter) and uptake of nutrients by the wheat crop. While the details would vary with soil and climatic conditions, the general trend of events may be presented as follows.

Leaves and stems continue to increase in dry matter up to and after ear emergence. As the increase in the dry weight of the ears is much larger than the decrease in weight of stems and leaves, it appears that although some material from stems and leaves may be translocated to ears, the greater portion of increased dry matter is absorbed and manufactured by the plant and then translocated to the ear.

The plant, therefore, apparently continues to absorb inorganic materials and manufacture organic matter until it matures.

Miller (1939), during one of his studies, observed that while nitrogen absorption continued for four weeks after earing and although the stems and leaves lost nitrogen to the ears, the gain in the ears was much greater, thus, indicating that some nitrogen from the soil passes directly to the ears. However, in another season Miller did not find any absorption of nitrogen after earing and the loss from the stems and leaves was even greater than the gain by the ears. Phosphorus increased generally from the seedling stage until harvest and it appeared that part of the phosphorus migrating to the ears came directly from the soil. The maximal content of potassium was attained considerably before harvest and then declined markedly. In one season the maximal content was reached at harvest. The increase in the potassium content in the ears was markedly less than the loss from stems and leaves (with two exceptions). In the exceptional cases the loss from the shoots was equal to the gain in the ears.

Asana, Mani and Malkani (unpublished) studied the growth and uptake of nitrogen, phosphorus and potassium by the variety N.P. 165 over a period of four seasons under Delhi conditions. The crop was grown in a plot 0·1 acre in area (net plot size) which was maintained throughout under uniform manurial and cultural conditions. Plant samples were collected at random on each occasion from 15 six-inch long strips; thus, the values indicated in Fig. 11 are based on plant material collected from a total length of seven and a half feet. The results obtained in one season when plant samples were collected at weekly intervals, beginning at three weeks after sowing, are discussed briefly in order to illustrate trends in accumulation of dry matter and of N, P and K in various plant parts.

The maximum shoot number was attained as early as five weeks after sowing and, thereafter, a more or less constant number was maintained until maturity. Maximum green-leaf weight was attained by ten weeks after sowing and, thereafter, a more or less constant level was maintained until about 17 weeks, after which the leaf weight diminished.

The plant continued to increase in dry matter for nearly three weeks after the commencement of ear emergence. The stem weight increased with time in a more or less similar manner but the ear weight continued to increase longer, i.e., for another four weeks or so. The stem weight remained more or less constant between 15 and 17 weeks and so also the green-leaf and dry-leaf weight. During this period the ear increased in weight substantially possibly as a result of photosynthesis in the shoot and the ear. Between 17 and 19 weeks there was some loss in shoot weight and gain in ear weight, while the total dry matter content of green and dry leaves remained more or less unchanged. It is difficult to judge from these data whether the ears gained in dry matter at the expense of that of the stem during this period. Apparently high sampling error was involved in the final sample at the 20th week after sowing since the stem as well as the ear showed considerable loss of weight.

The nitrogen content of the plant increased steadily until about nine weeks after sowing, but the rate of increase slowed down considerably during the next four weeks; thereafter, absorption increased sharply and continued for another two weeks. There was little increase in the nitrogen content of the whole plant after 15 weeks. Ear emergence commenced 12 weeks after sowing. Between 12 and 15 weeks the

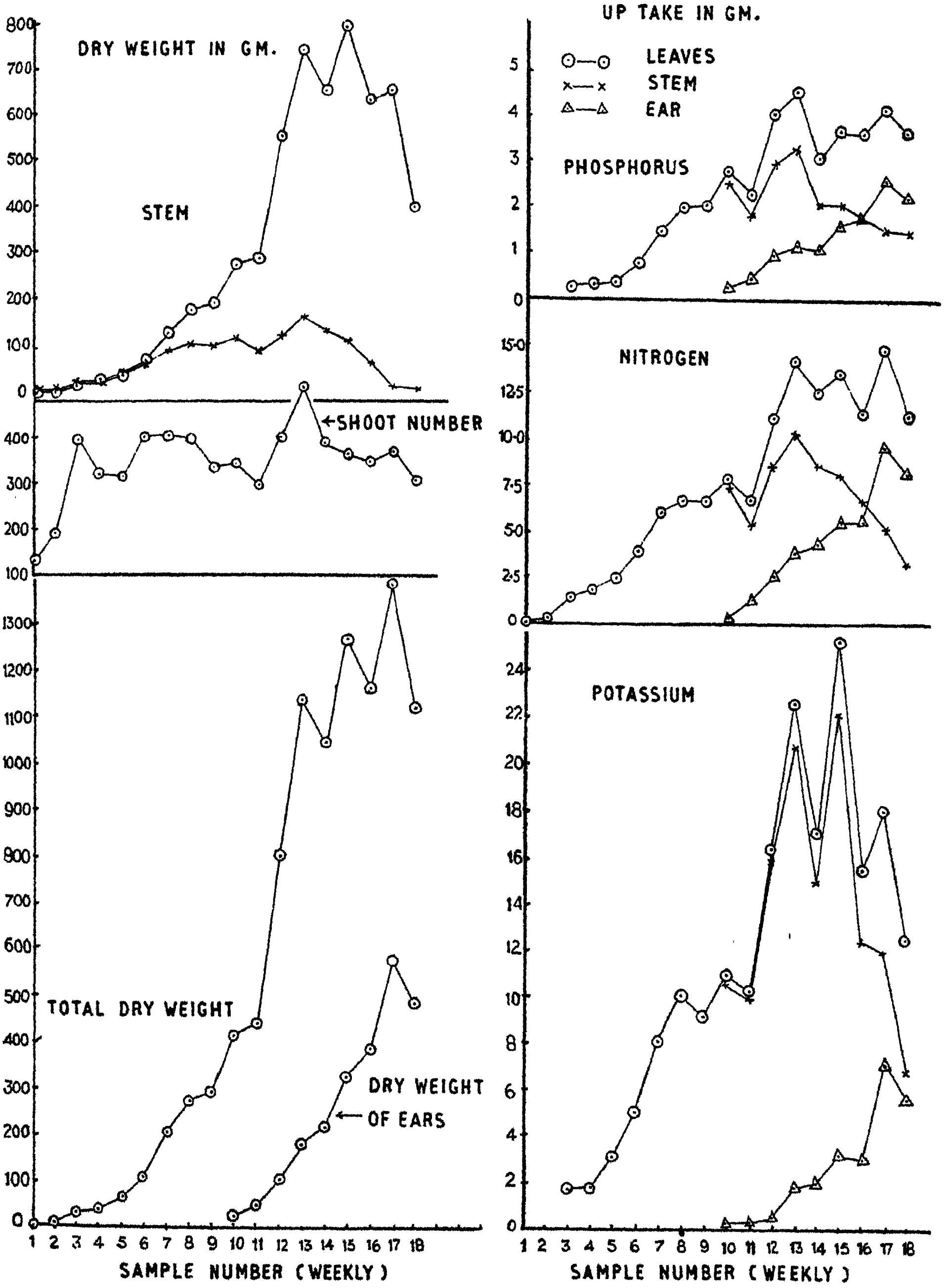

FIG. 11. Growth (increase of stem, leaf, ear and total plant dry weight in grams) and uptake of N, P and K (in grams per length of 7·5 ft.) in weekly samples

nitrogen content of the shoot (stem and leaves), as also of the ear, increased; thus, indicating that some nitrogen from the soil was directly transferred to the ear; after 15 weeks the nitrogen content of the ears increased steadily, whereas that of the shoot decreased, thereby indicating that nitrogen in the ear increased at the expense of the nitrogen content of the shoot.

The trends in the absorption of phosphorus and its accumulation were exactly similar to those in the case of nitrogen.

The potassium content of the plant increased steadily until ten weeks after sowing; the rate of increase slowed down appreciably for another three weeks, then increased sharply and absorption continued for another two weeks. There was some indication of loss of potassium from the plant during the last two weeks. It would appear that some potassium from the soil was directly transferred to the ear until about 17 weeks after sowing and that only later some potassium from the shoot migrated to the ear.

Varietal differences in uptake of nitrogen. Malkani (unpublished) studied the uptake of nitrogen by three varieties of wheat, N.P. 52, N.P. 165 and N.P. 710, over a period of four seasons at 0, 20 and 40 lb. nitrogen per acre. No varietal differences in the uptake of nitrogen or in response to nitrogen levels were observed.

Physiological causes of varietal differences in yield. Over 35 years ago, Engledow initiated a study of characters which could be quantitatively measured and, thus, utilized for more scientific breeding of cereals. Engledow and Wadham (1923) stated that " the procedure should be to find out the plant characters which control yield per acre and by a synthetic system of hybridization to accumulate into one plant form the optimum combination of yield-controlling factors ". The characters which were studied for this purpose were: number of plants per unit area, number of tillers per plant, shoot height, number of ears per plant, number of grains per ear and weight per grain. Investigations on similar lines were also undertaken by Forster and Vasey (1931), Frankel (1935) and Stephens (1942). These yield characters did not, however, offer a simple basis for selection in view of some inverse correlations between them.

Engledow and Wadham (1923) fully realized that measurement of morphological characters shed little light on the underlying physiological causes governing yield, for, they remarked " to plant physiology we must look for the final solution of the yield problem ". Worzella (1941) also suggested that long- and short-season plants, tall and short varieties, wide and narrow leaves, rate of growth, sterility, intensity of chlorophyll, etc., may be inherent factors affecting yield. He had apparently in mind differential assimilatory activity of the varieties when he emphasized such factors as plant height, leaf width and chlorophyll concentration.

Boonstra (1929) was perhaps the first to suggest a physiological cause of varietal difference in yield when he accounted for variation in yield of four varieties of oats on the basis of differential longevity of their leaves. Later, Boonstra (1931), Smith (1933), Watson and Norman (1939), and Archbold (1942) found that in cereals assimilation by stems and ears contributed substantially to grain yield.

Asana and Mani (1950), working at the Indian Agricultural Research Institute, showed that varieties of wheat differed in respect of contribution by photosynthesis in ear to dry matter production and yield and suggested that this may have a bearing on varietal differences in yield under rust infection. Asana and Mani (1955) further observed that seasonal variation in contribution from ear to dry matter production was much smaller than that from the foliage and stem.

The technique of estimating the contribution from photosynthesis in different organs to grain yield, adopted by the workers mentioned above, consisted in shading the organs or defoliating and noting the reduction in yield. This was obviously an indirect method and one which did not take into account the effect of wounding in defoliation and that of shading on other processes besides photosynthesis. Porter *et al.* (1950) estimated, therefore, assimilation and respiration of the ear of barley throughout its ontogeny and concluded that photosynthesis by the ear contributed an important share to grain weight inasmuch as the net amount of CO_2 absorbed accounted for all the starch content of the grain. Asana and his co-workers followed the rate of increase in grain weight along with the change in time of the green surface of the shoot and the ear in a number of varieties of wheat in pot as well as field culture and under adequate and deficient soil moisture. The experimental technique did not involve defoliation or shading and soil moisture was included as another factor in order to investigate the effect of drought on the relative senescence of the varieties and on yield. Intermittent drought was given from dehiscence onward since under unirrigated conditions at Delhi and elsewhere moisture stress becomes particularly acute during the period of grain-filling. The observations of Asana and Mani (1958), Asana and Ray (1958), and Asana and Saini (1958), along with a few unpublished observations of the latter authors, are briefly reviewed below (for a generalized picture of events *see* Fig. 12).

The extension growth of the peduncle was suppressed by drought, whereas the size of leaves and ear was not influenced as their growth was completed before drought commenced.

Under drought the water content of the ear was reduced only to a negligible extent even when the leaves were at the permanent wilting stage. Once yellowing started (at a later stage), it progressed more rapidly in the ear under drought.

During the first four weeks or so after dehiscence, grains increased in weight at the same rate under normal water supply and drought. Grain number per ear was reduced under drought, whereas 1,000-grain weight was slightly increased during this period. Apparently the food supply was unaffected by drought, although the green surface of leaves and stem was definitely reduced (that of the ear being unaffected). It may be mentioned that stem suffers reduction in dry weight from about two to three weeks onward after dehiscence. A considerable portion of this reduction in dry matter is due to sugars which may appear to migrate to the ear. In fact, the total reduction in dry matter of the shoot could account for barely 30 per cent of the increase in grain weight under drought and 5 per cent under normal water supply. Evidently, supply from current photosynthesis, therefore, plays a major role in grain-filling during this period.

About four weeks after dehiscence, grains increased in size at a faster rate under normal water supply; thus, the ultimate difference in weight per grain and yield was brought about in favour of this treatment. During this period, leaves and stem were nearly yellow, while the ear yellowed more quickly under drought. Apparently, the green surface of the ear (and, therefore, photosynthesis) largely controlled grain-filling. During this period the decrease in the sugar content of the stem was considerable and it may well be questioned as to how much of it was translocated to the ear. Two observations indicated that only a small proportion of the stem sugar could have contributed to grain-filling: (i) There was little consistent parallelism between the rates of increase in the starch content of the grains and the rates of decrease in stem sugar; (ii) comparison of rates of decrease in the sugar content of stems with and without ears indicated only slightly greater rates of loss in the former and if this difference was

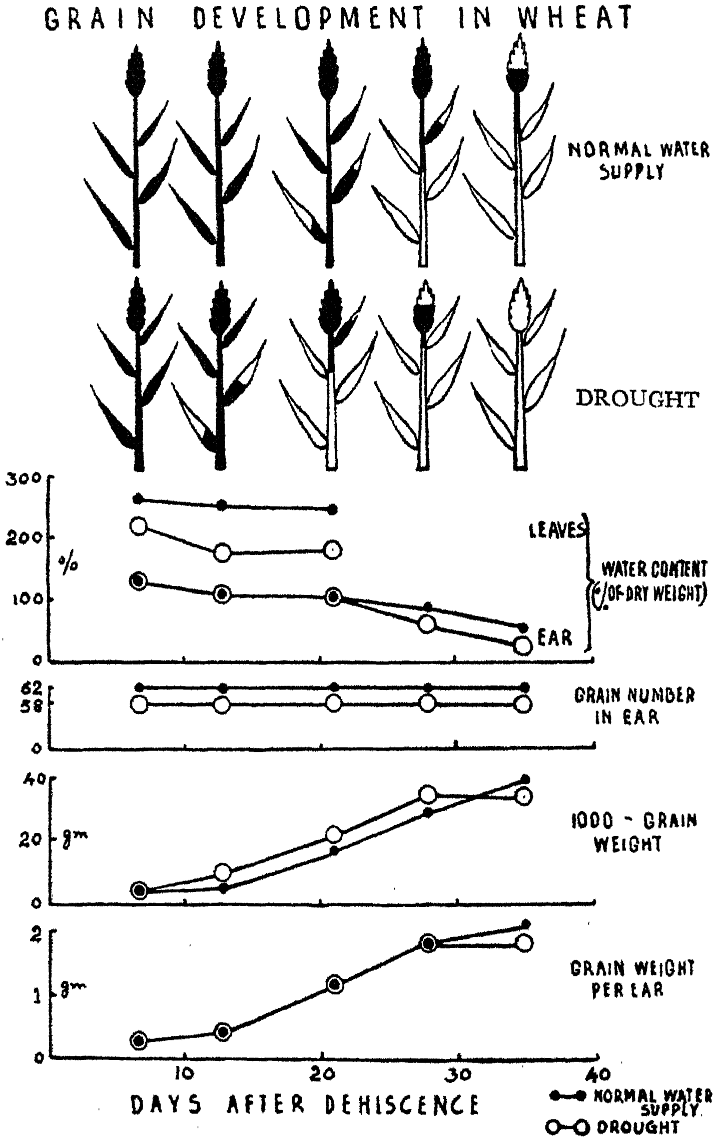

FIG. 12. Grain development in wheat. The effect of normal and restricted water supply on the rate of yellowing of different organs (shaded=green; unshaded=yellow), water contents of leaves and ears, grain number per ear, 1,000-grain weight and grain weight per ear. (*After* Asana, 1958).

attributed to translocation to the ear, the total amount translocated barely accounted for 10 per cent of the total starch content of the grain.

Comparison of varieties indicated similar trends as obtaining under differential water supply; that is, a variety with a higher grain weight per ear due to its larger 1,000-grain weight (grain number being equal) showed increase in 1,000-grain weight over the other variety, and, thus, outyielded the latter only during the last week and a half of the maturity period during which its ear yellowed at a slower rate. If this relationship could be shown to hold over a wider range of varieties, it could reasonably be generalized that photosynthetic activity of the ear and its duration play a crucial role in determining varietal differences in yield. Further, this finding would point to an index of yield, particularly for unirrigated conditions, where ear number does not appear to be the most potent factor determining yield (*cf.* Asana *et al.*, 1955; Asana and Mani, 1958).

LODGING

Lodging not only affects yield of wheat adversely but also renders harvesting laborious and expensive. Lodging may be attributed to : (i) weak straw with poorly developed mechanical tissue or inferior root system; (ii) heavy application of nitrogenous fertilizers and resulting unbalanced nutrition; (iii) thick sowing; (iv) wet soil due to waterlogging, irrigation or rainfall followed by strong wind; and (v) attack by pests and diseases. Attempts to correlate different plant characters with lodging have unfortunately led to inconsistent results, the characters chosen for study being erectness of leaf, amount of tillering, length of straw, weight per unit length of culm, breaking strength of straw, number of vascular bundles, percentage of lignin, yield of straw, yield of grain, depth of seeding, length of internodes, length of sclerenchymatous fibres and amount of silica.

Investigations were undertaken at the Botany Division of the Indian Agricultural Research Institute, New Delhi, by Malkani and his co-workers on varieties N.P. 12, N.P. 52, N.P. 710, N.P. 165 and Pb.C. 518; of these the first three are known from field experience to be more susceptible to lodging than the last two. These varieties were raised under low as well as high fertility over several seasons and the characters examined were: (i) the tiller number, (ii) the height of the main shoot, (iii) the number of internodes per main shoot, (iv) the length of the above-ground internode, (v) the diameter of the above-ground internode, (vi) the fresh and dry weight per unit length of above-ground internode, (vii) the breaking strength of the same internode, (viii) the ratio of breaking strength of the same internode to fresh weight of shoot, (ix) the number of vascular bundles, (x) the number of cells in the sclerenchyma of the above-ground internode, (xi) the fresh weight of shoot, and (xii) the silica content of the above-ground internode. The broad conclusions emerging from these investigations (Malkani and Vaidya, 1956; Malkani and Shrivastava, 1958; Malkani *et al.*, 1959) are indicated below.

In Table XX are presented data on ratios of breaking strength of above-ground internode to fresh weight of shoot and of shoot weight to root weight (from one cubic foot of soil), since these alone showed consistent associations with tendency to lodging.

It is seen that varieties N.P. 165 and Pb.C. 518 had higher ratios of breaking strength of above-ground internode to shoot weight and lower shoot weight to root

TABLE XX. RESISTANCE TO LODGING IN SOME VARIETIES OF BREAD WHEAT IN RELATION TO CERTAIN INDICES OF LODGING RESISTANCE

Variety	Field resistance to lodging	Breaking strength/ shoot weight	Shoot weight/root weight
		(Minimal and maximal values)	
N.P. 165	Fair	83–105	10–15
Pb. C. 518	,,	88–102	9–18
N.P. 710	Low	61–76	11–22
N.P. 52	,,	61–75	17–24
N.P. 12	,,	80–95	13–21

weight ratios, thus indicating that in these two varieties the internode had relatively greater strength to support the weight of the shoot and that anchorage provided by the root system in relation to shoot weight was relatively better than was the case with the other three varieties. It appears that these two ratios together would provide a very suitable index of lodging resistance.

As regards the application of these indices for the purpose of selection of varieties resistant to lodging, it is obvious that the shoot/root ratio is not suitable, involving as it does, destruction of the clump and considerable labour and time. For the determination of the other ratio the whole clump need not be sampled, as it would suffice to make observations on one or two ear-bearing shoots and fix a lower limit of 100 as a standard.

It was also observed, as a result of several trials, that if nitrogen applications were deferred to about ten weeks after sowing, lodging was substantially reduced and this compensated sufficiently for the risk of some reduction in yield (as compared to that obtained with application of nitrogen at sowing and without lodging).

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X

DISEASES

RUSTS

Although wheat, like all other cereals, is attacked by a large number of plant pathogens, the rust fungi are considered to be the most destructive among them. The rust diseases have menaced the wheat crop all over the world since ancient times. It is reported that in ancient Italy prayers were offered to the Rust gods, Rubigus and Robigo, for the protection of the wheat crop against the ravages of the rust disease. Aristotle, Theophrastus, Eresius and other Greek authors have recorded the occurrence of rust on wheat; this they attributed variously to warmth, moisture, sunshine following dew, and the warmth of the moon. Farmers in the Greek islands of Rhodes and Cyprus used to pray to Apollo to diminish rust (Chester, 1946). In India too rust is by no means a modern malady in the wheat fields. Sleeman in 1839, speaking of rust in the Central Provinces (now Madhya Pradesh) reported: " I have seen rich sheets of uninterrupted wheat cultivation for twenty miles by ten in the valley of Narbudda so entirely destroyed by this disease that the people would not go to the cost of gathering one field in four "; further: " I believe that the total amount of the wheat gathered in the harvest of 1827 in the District of Jubbulpore was not equal to the quantity of seed that had been sown ".

The annual loss caused by the rust fungi amounts approximately to 600,000,000 bushels (about 460,000,000 maunds) throughout the world. In some advanced countries, the loss caused by the rust has been estimated very carefully. Thus, in 1935, the loss caused by it in the U.S.A. was stated to be 132,045,000 bushels (about 100,000,000 maunds). In the same year, in Canada the loss was estimated to be over 91 million bushels (more than 70 million maunds). In India, no reliable estimates of overall losses on account of rusts are available but it has been demonstrated experimentally that loss in grain weight could be anything between 10 and 50 per cent, depending on the time and intensity of attack and the variety concerned (Vasudeva, 1954). At the end of the last century, Dr. Barclay (Butler and Hayman, 1906) estimated that the loss to the wheat crop due to rusts was four crores of rupees (40 million rupees) annually, and Mehta (1950) calculated it to be 200 million rupees per year on the wheat prices then current. In 1947, a severe outbreak of the rust in Madhya Pradesh (then known as Central Provinces) destroyed nearly two million tons of wheat grain and brought near famine conditions in several parts of the country.

Wheat in India is attacked by all the three rusts, namely, the black or stem rust [*Puccinia graminis tritici* (Pers.) Erikss. & Henn.], the brown or leaf rust (*Puccinia recondita* Rob. ex Desm.), and the yellow or stripe rust [*P. glumarum* (Schmidt) Erikss. & Henn.]. A brief account of each is given in the following pages.

Black or stem rust [*Puccinia graminis tritici* (Pers.) Erikss. & Henn.]. Black rust of wheat is prevalent throughout the country wherever wheat is cultivated. In the hills, it has been observed even at altitudes of 10,000 feet and this appears to be the highest level of wheat cultivation in India. In the plains, it appears usually late in the season, particularly in areas which are far away from the hills. The first symptom of the disease under field conditions is the appearance of small brownish-coloured pustules in the aerial parts of the plants, particularly on the lower leaves, the leaf sheaths, and the stem. These pustules gradually enlarge and coalesce with each other, forming big lesions of dark-brown colour, covered by a membranous epidermis, which ruptures as the pustules enlarge, releasing a fine powdery mass of brown spores. Even at a later stage the remnants of epidermis are seen on the fringes of the well-developed pustules. In case of serious attacks, clouds of uredospores are produced. The severely attacked plants have a tendency to lodge easily. In the later stages of infection dark-coloured teleutospores are produced in the pustules which gradually turn black in colour, and for this reason the rust is commonly known as the 'Black Rust' (Plate 69).

The infected foliar tissues die earlier than the healthy ones, and in case of severe rust attack the plant size is reduced, tillering is poor, and the grains get shrivelled and are light in weight. In extreme cases the grain is not formed at all. The rusted straw becomes dry and brittle and breaks off easily. It has also been recorded that the water requirement of rusted plants is much higher than that of healthy ones.

The pustules are formed on the mycelium which extends within the tissues of the host plant. The hyphae ramify between the cells and send branched haustoria into them. As the infection grows older the hyphae get accumulated below the epidermis and eventually form a new pustule containing oval uredospores borne on stalks. The uredospores are echinulate, oval in shape, 25 to 30 $\mu \times 17$ to 20 μ, brown in colour and have four equatorial germ pores. The germ pores are not usually easily visible but they become clear just before the initiation of germination of the uredospores. Teleutospores are black in colour, bi-celled, pedicellate, 40 to 60 $\mu \times 15$ to 20 μ. The germ pore of the upper cell is at the tip and that of the lower just below the septum. The apex is rounded or pointed, very rarely flattened, and is much thicker than the side walls.

The uredospores of the rust germinate readily after their release if environmental conditions, such as rain or heavy dew and a temperature ranging from 55° to 75°F, are available. Normally the uredospores put forth only one germ tube but at times two or more germ tubes appear from different germ pores of the same uredospore. The teleutospores, on maturation, germinate by producing a promycelium; on this are borne four sporidia.

Puccinia graminis tritici is a heteroecious, full-cycle rust. Uredo- and teleuto-stages occur on cereals and allied grasses, and pycnial and aecidial stages on barberries. Craigie (1927) discovered the function of pycnia and demonstrated that the rust is heterothallic.

Existence of physiologic races was first demonstrated by Stakman and Piemeisel (1917) and since then a large number of physiologic races have been identified. According to Stakman and Harrar (1957), the number of races so far recorded all over the world is more than 250. In India the work on physiologic races was initiated by Mehta in 1932, and he recorded the occurrence of races 15, 21, 24, 40, 42 and 75 till 1940. So far 12 races and four biotypes have been recorded by different workers; these are: races 15, 15C, 17, 21, 21A, 24, 34, 40, 42, 42A, 42B, 72, 75, 117, 122 and 194.

Brown rust (*Puccinia recondita* Rob. ex Desm.). As the names 'leaf rust' or 'brown rust' suggest, the fungus is mainly restricted to the leaves and produces spores of light brown colour on the infected parts. This stage, however, is not restricted to the leaf blade alone but in cases of severe infection may be found on leaf sheaths, glumes and awns as well. In certain parts of the country, such as Bengal, Bihar and Uttar Pradesh, this rust is the first to appear on the crop (Butler, 1918). In the Punjab, however, yellow rust makes its appearance first and brown rust follows it.

The uredo-pustules first appear on the upper surface of the leaf blade and are light orange in colour. Later these may be found on both the surfaces of the leaf, though these are most common on the upper surface. At first these are sub-epidermal but soon the epidermis ruptures with longitudinal slits and brown powdery uredo-dust is exposed and is easily disseminated by wind currents. The teleuto-stage, on the other hand, is found mostly on the lower surface. The uredo-pustules, as a rule, are never in rows but are scattered irregularly on the leaf surface. There is no discolouration of the surrounding tissue in the early stages of development but later the leaves become completely, or at least partially, yellow. The uredial size is much smaller than that of black rust, being only 0·5 to 2·3 mm. If pustules are few and scattered, these get surrounded by a partial or complete circle of smaller uredia.

The teleutospores of the rust, unlike those of black rust, remain covered by the epidermis and are lead-grey in colour. Invariably, these are found on the dying or dead leaves of the plant. It appears that their formation is dependent on the environmental conditions; hence, they do not appear every year. Butler (1918) reported that these were quite common in 1904. Prasada (1948a) observed that the teleutospores are formed readily on wheat N.P. 114. Each has a flattened top and a thick wall.

In case of severe attack the disease leads to premature death of the plant. Due to the interference with the photosynthetic activity of the plant, the normal formation of the grains is hindered and grains get shrivelled. In severe epiphytotics the plants are reduced to half their normal size and the root system also deteriorates. According to Pal (1936), brown and yellow rusts cause principal damage since black rust is usually too late to be injurious.

Jackson and Mains (1921) found that the aecidial stage of this rust is formed on certain species of *Thalictrum* under artificial infection and suggested that it may act as the alternate host. However, there is no case on record where *Thalictrum* has been found to act as a natural alternate host in any country. Recently, Levine and Hildreth (1957) observed a case of natural infection of *Thalictrum* with *Puccinia recondita* in a place near Minnesota (U.S.A.) but considered it an exception rather than the rule. From Russia, Bryzgalova (1937) reported that *Isopyron fumarioides* acts as a natural alternate host in eastern Siberia.

The existence of physiologic races in *Puccinia recondita* was first reported by Mains and Jackson (1926), who isolated 12 races with different reactions on 11 wheat varieties in the U.S.A. Since then these differential hosts (reduced to eight in 1932) have been used universally and in all 163 races have been reported up to now. In India, twelve races have been identified. These are: races 10, 11, 17, 20, 26, 53, 70, 77, 106, 107, 108 and 162.

Yellow rust [*Puccinia glumarum* **(Schmidt) Erikss. & Henn.]**. This rust is easily distinguishable from the two rusts of wheat discussed above by its colour. In Delhi and other places in the Punjab, it is the first rust to appear on the wheat crop; but in Bengal, Bihar and certain parts of Uttar Pradesh (formerly known as the United Provinces) it appears after the brown rust. Unlike the other two rusts, it has a restricted distribution and it is prevalent mainly in the North. From the South, it has been recorded from the Nilgiri and Palni hills. In the North, particularly in the Punjab and parts of U.P., it appears in a virulent form and causes considerable damage to the crop. It appears that its distribution is governed by the environmental conditions and the rust is more severe in those parts of the country where temperatures are very low during the wheat-growing season.

The rust is characterized by small pinhead-like pustules of yellow colour, running in streaks, hence the common name ' stripe rust '. In case of mild attack the uredo-pustules are chiefly found on the leaf blade but in more serious cases they may appear on the sheath, stalk, glumes, awns and even on grains. The streaks consist of a number of pustules arranged along the veins. In case of severe infections, the streaks, however, are not easily distinguishable as the pustules are crowded together. The uredospores are produced in such a great abundance that the soil below the wheat plants turns yellow. The infected leaves mature earlier than the healthy ones and give a ' dried-up ' appearance to the whole infected field when viewed from a distance.

The teleuto-pustules appear as dull black-coloured streaks, or as broad columns running throughout the length of the leaf blade if the infection is severe. Dull black streaks are formed mainly on the undersurface of the infected leaves. Unlike in brown rust, the formation of teleutospores in yellow rust is a normal phenomenon. In fact, the teleutospores appear very readily if environmental conditions are adverse. Usually they appear on the leaves but at times they are found on other parts also. The pustules remain covered by the epidermis. The teleutospores are bi-celled, pedicellate, and have a flat top.

The uredospores, unlike those in black rust, are nearly round and measure 23–35 $\mu \times 20$–35 μ, with five spines and a hyaline wall. Usually there are six to ten germ pores. The uredospores germinate by producing small fragile hyphae from the germ pores. Usually a spore produces only a single germ-tube. The full life-cycle of the rust still remains unknown since an alternate host has not been found.

Mode of perpetuation. The mode of perpetuation, of all the three rusts of wheat, is more or less the same in India. In the plains, where 95 per cent of the total wheat is cultivated, no species of *Berberis* or *Thalictrum* are found to occur, and as such the question of their infection does not arise. Mehta's studies have shown that the teleutospores of the rusts cannot survive even in the hills up to 7,000 feet above sea-level and, therefore, they cannot play any part in the annual recurrence of the disease. In the hills, species of *Berberis* and *Thalictrum* are common above 3,000 ft. and this led Barclay (1887) to conclude that the common aecidial stage occurring in the hills was connected with the black rust of wheat. Butler and Hayman (1906) made some preliminary studies and felt that Barclay's observations might not be quite correct. Later, Butler (1918) established that the aecidial stage occurring in the hills on *Berberis* was not connected with black rust of wheat at all. Mehta (1923, 1929, 1931,1940) carried out a detailed study on the role of alternate hosts and the mode of perpetuation of the rusts and concluded that the species of *Berberis* and *Thalictrum* occurring in the hills play very little part in the annual recurrence of the rusts in the plains.

According to Mehta, the rusts oversummer in the uredo-stage either on self-sown plants or ratoon tillers and out-of-season plants, at suitable altitudes in the hills of the Himalayan range in the North. In the South in the Nilgiri and Palni hills, wheat is sown both as a winter as well as a summer crop and serves as a focus of infection because a suitable host is available practically all the year round. From these foci of infection the spores are wafted down to the plains by wind currents. In the plains, on the other hand, the rusts cannot survive either as uredospores or teleutospores during summer months with the result that there is no local source of infection. The outbreak of rusts two or three months, sometimes even four months, after the sowing of wheat crop, even though the conditions are congenial for the development of rusts in the months of October and November, lends additional support to the view that there is no local source of infection in the plains.

It is well known that in cold countries teleutospores of stem rust are produced in autumn and they remain buried in snow during the winter months. On the return of spring, the dormant teleutospores become active and germinate profusely producing in great abundance sporidia which infect *Berberis*. In India, however, conditions are significantly different as the teleutospores are formed at the end of spring or the beginning of summer, depending upon environmental conditions. Therefore, in this country, the teleutospores represent the summer stage and not the winter stage; and after formation they remain exposed to summer temperatures. Teleutospores formed under and exposed to such conditions cannot retain their viability. Lambert (1929) observed that the viability of the teleutospores formed in May and June in the States of Texas, Oklahoma, S. Kansas, etc., is lost during the summer months. Stakman *et al.* (1921) also stated that the teleutospores formed in the northern States of U.S.A. failed to infect the *Berberis* bushes if they are kept in the South. It may be mentioned here that it is not only the prevalence of high temperature to which the material is exposed that decides the viability of the material but even the temperature prevalent at the time of their formation plays a very significant part in determining its viability. Johnson (1931) observed that the teleutospores formed at 50° to 60°F germinated better than those formed at 70° to 75°F.

Judging the position on the basis of these records and the information collected by Mehta, it is evident that the teleutospores formed in the plains of India, even if viable at the time of their formation, cannot retain their viability and, as such, they have no part to play in the life-cycle of the fungus. "The conditions eliminate, altogether, the possibility of any infection of *Berberis* in the hills, and there are none in the plains, by such teleutospores as may be blown by wind from the latter" (Mehta, 1940). Even in the hills, according to him, the teleutospores of the rust formed at altitudes below 7,000 ft. are not usually viable and there is very little viable material of the teleutospores from regular crops. The scarcity of viable material and the climatic

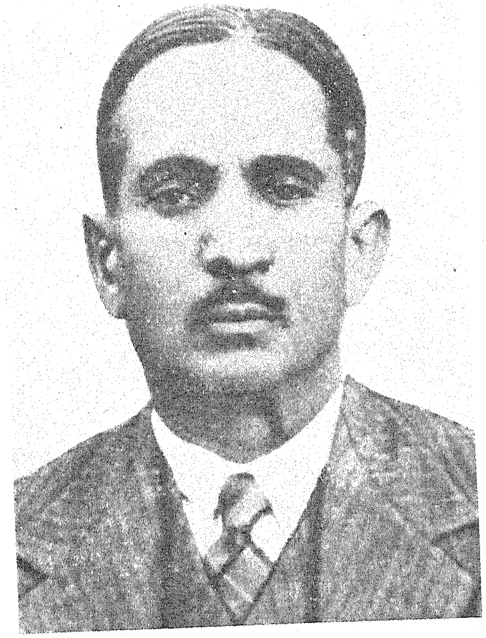

Plate 63. Dr. K. C. Mehta

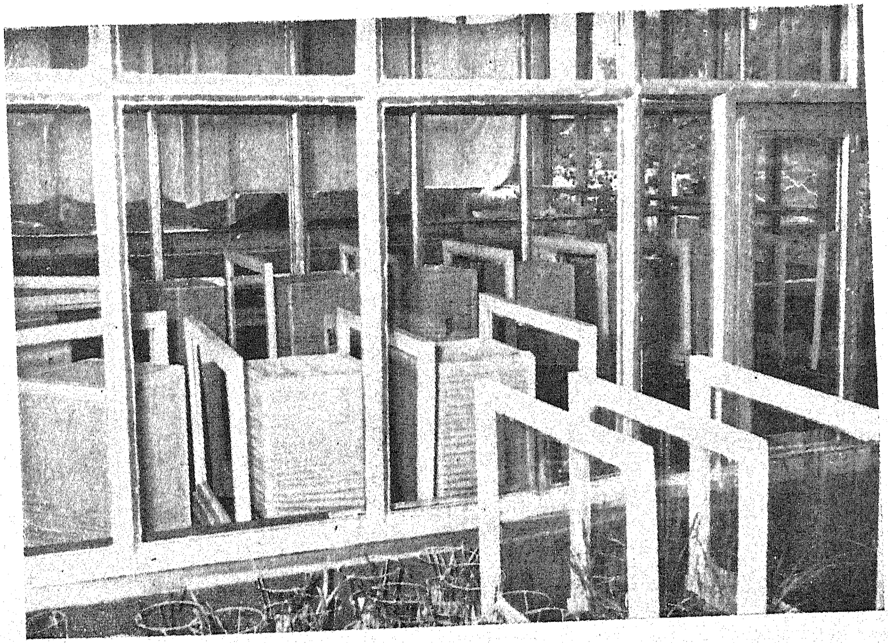

Plate 64. Interior of the rust glass-house. Single-spore cultures covered with muslin chambers are seen in the background

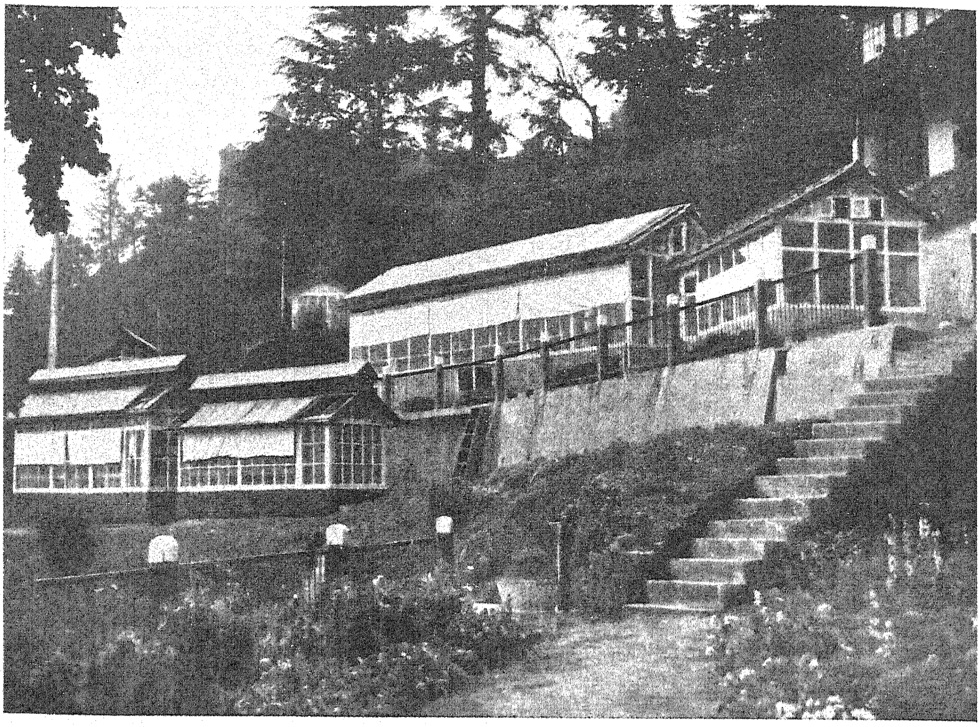

Plate 65. Mycological substation of the Indian Agricultural Research Institute, Simla

conditions prevalent in the hills (up to 7,000 ft. a.s.l.) during March to May appear to be chiefly responsible for the absence of infection on *Berberis*. However, the teleuto material formed at these heights, 7,000 ft. and above, in early winter months, when the temperature conditions are most favourable for their development on self-sown plants that carry over the rust in uredo-stage, has been found to be quite viable and it is possible that under congenial weather conditions they might infect *Berberis*. However, extensive search for the occurrence of the aecidial stage of black and brown rusts of wheat in the hills have so far given no evidence to support the belief that infection of the alternate hosts takes place under natural conditions.

Barclay (1887) recorded the occurrence of the aecidial stage on *Berberis* sp. in the hills. Butler (1905) confirmed his findings and also stated that "around Simla *Aecidium berberidis* undoubtedly occurs on *B. lycium* and probably on *B. coriaria* Royle, *B. aristata* DC. and a species which has been undoubtedly referred to *B. umbellata* Wall. It probably also occurs on *B. vulgaris* to the west of Simla, where alone this species is found". He, however, felt that the aecidium was not allied to black rust of cereals and probably belonged to some other specialized form of the parasite. He (1918) reported that the barberry aeciospores in Kumaon could not be got to infect wheat and probably belong to some other race of the parasite. Mehta (1923, 1929, 1940), apart from the reason already given above, has put forward the following arguments to support his view that *Berberis* and *Thalictrum*, the alternate hosts of black and brown rusts of wheat, respectively, play little or no part at all in the annual recurrence of the rusts in the plains of India :

(i) The most susceptible species of *Berberis*, i.e., *B. vulgaris*, does not occur in India. Amongst the indigenous species of *Berberis* in Simla Hills, *B. lycium* and *B. coriaria* are just moderately susceptible. In case of brown rust *Thalictrum javanicum* is artificially infected in the laboratory.

(ii) As mentioned above, the teleutospores formed in the plains and above 7,000 ft. on regular crops are not usually viable and as such there is scarcity of viable material even in the hills, where alone the alternate hosts exist.

(iii) The weather conditions in the months of March to May in the hills are comparatively dry and as such the teleutospores, even if they were viable, would not normally germinate readily.

(iv) Infection of susceptible species of *Berberis* and *Thalictrum* can take place only when the leaves are young. In the hills new leaves appear in early spring. Even if it is presumed that they get infected by the limited viable material that is available there, the infection from them cannot reach the plains before April or May and by that time most of the crop is harvested. Black rust has been found to break out, year after year, at several places in the plains as early as December-January, i.e., two to three months ahead of the possible infection of *Berberis* in the hills.

(v) So far no scientific data are available to prove that the common aecidia occurring on *Berberis* and *Thalictrum* spp. in the hills are connected with the rusts of wheat. In fact Prasada (1947, 1948b) has shown that the common aecidial stage of *Berberis* (*Aecidium berberidis*) is connected with *Agropyron* rust (*Puccinia graminis agropyri*) and the *Thalictrum* aecidium with *Puccinia persistens*.

(vi) The number of physiologic races is not as large as can be expected if alternate hosts were functional.

On the basis of these observations, Mehta concluded that alternate hosts play very little or no part in the annual recurrence of the disease in this country. The rusts of wheat perpetuate in the Himalayas in the North, between altitudes of 4,000 to 8,000 feet, on self-sown plants, ratoon tillers and 'volunteer' wheats in the form of oversummering uredospores. Black and brown rust uredospores can normally oversummer at altitudes of 4,500 ft. and above and may even survive, at least occasionally, even at lower altitudes of 3,000 to 4,000 ft. Mehta (1933) has recorded the occurrence of these rusts at several places on the banks of rivers in the Kumaon Hills at altitudes of 3,500 to 4,000 ft. during the hottest parts of the year, i.e., May and June. Yellow rust of wheat does not normally oversummer below an altitude of 6,000 ft. as its uredospores suffer most from heat.

In central Nepal, wheat is sown in August or September and invariably the crop gets an early attack of rust. As early as December, 20 to 40 per cent crop infection has been observed. Therefore, one of the important foci of infection for the crops of North India is probably central Nepal. In the South, the Nilgiri and Palni hills have got ideal climatic conditions for the oversummering of all the three rusts. Moreover, as already mentioned in the preceding pages, two crops of wheat are taken in one year. Therefore, a congenial host is available practically all the year round, and the uredo-stage of all the three rusts is found on them.

Oversummering or overwintering of the uredospores is by no means a rare phenomenon. Plowright (1882) stated that in England uredospores of *P. rubigovera* survive all the year round. Mehta (1923) observed that yellow rust overwinters in the uredo-stage in the neighbourhood of Cambridge. Foster and Henry (1937) pointed out that the uredospores of *P. glumarum* are capable of surviving in winter months in Alberta. Peltier (1929) recorded that stem rust can overwinter in the southern States of the U.S.A. In India, many workers (Butler and Hayman, 1906; Butler, 1918; Mehta, 1929) observed that the uredospores of wheat rusts cannot survive in the plains during summer months. Butler (1918) had observed that five-minute exposure to moist heat at 45°C or even direct exposure to sun, when the shade temperature is about 95°F, is enough to kill the uredospores of yellow rust. On the other hand, oversummering as well as overwintering of the uredospores can take place at suitable heights in the hills. It has been recorded by Mehta (1929, 1940) that year after year the rusts in Uttar Pradesh appeared first in the foothills on Nepal border. In the South, infection of black rust has been observed in the experimental plots laid at the foot of the hills (at Mandya and Coimbatore) much earlier than in other places. On the other hand, in places far off from the foci of infection, the rust appears at a much later date. In Delhi and Agra black rust invariably appears in January, almost three months after the sowings.

Regarding the dissemination of rust spores by air currents, Mehta (1952) carried out detailed studies with the help of stationary slides exposed in aeroscopes, slides sent up in kites and balloons and nearly 11,000 wind trajectories. Data obtained from these studies show that the spore showers took place at most of the stations well in advance of the local outbreak of rusts. He also concluded that as far as the initial outbreak of rusts in the plains is concerned, the foci in the North and South seem to be circumscribed.

Collateral hosts. Grasses are known to be collateral hosts of wheat rusts, and a considerable amount of information is available in literature concerning their

PLATE 66. Spraying rust inoculum in the field

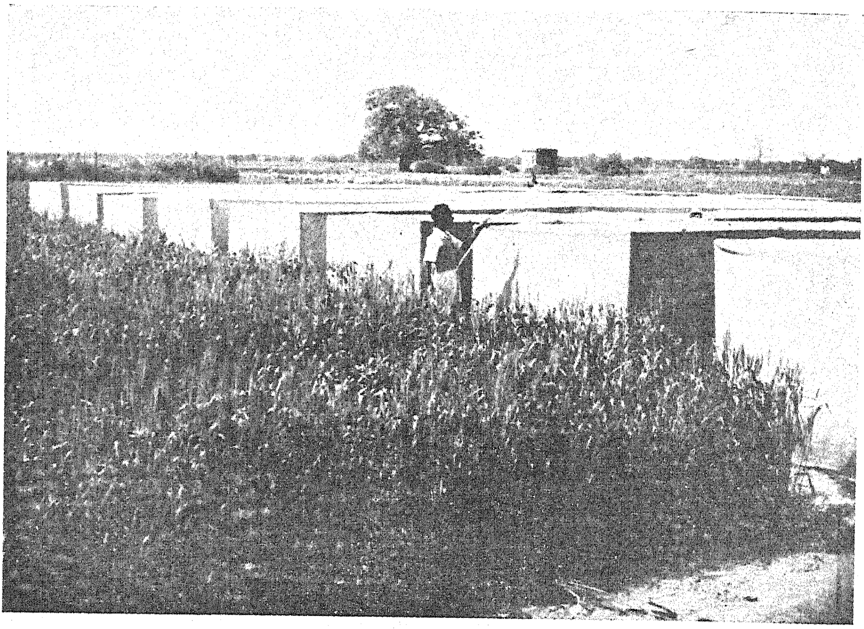

PLATE 67. Maintaining humidity around infected plots. The plots are covered with muslin tents which are sprayed with water to keep them moist.

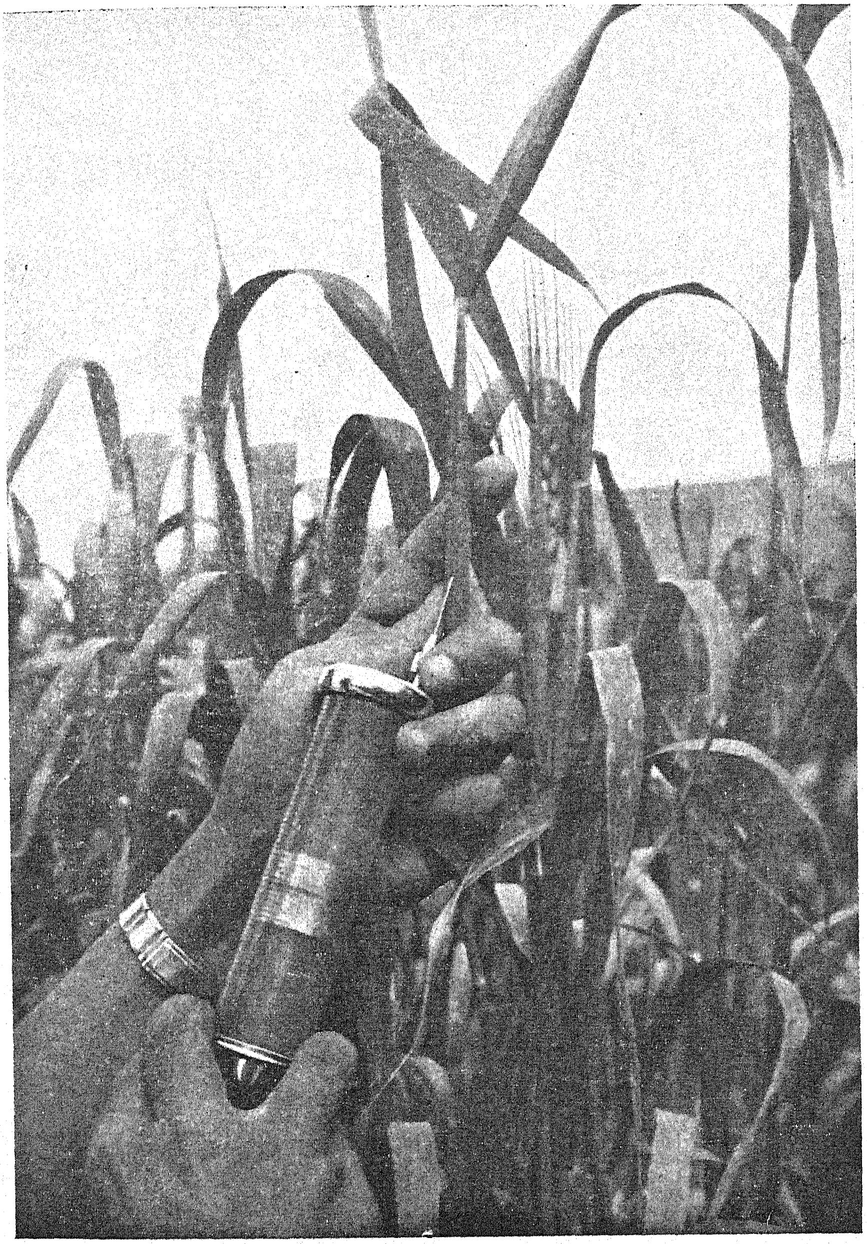

PLATE 68. Rust inoculation at boot stage by injecting spore suspension

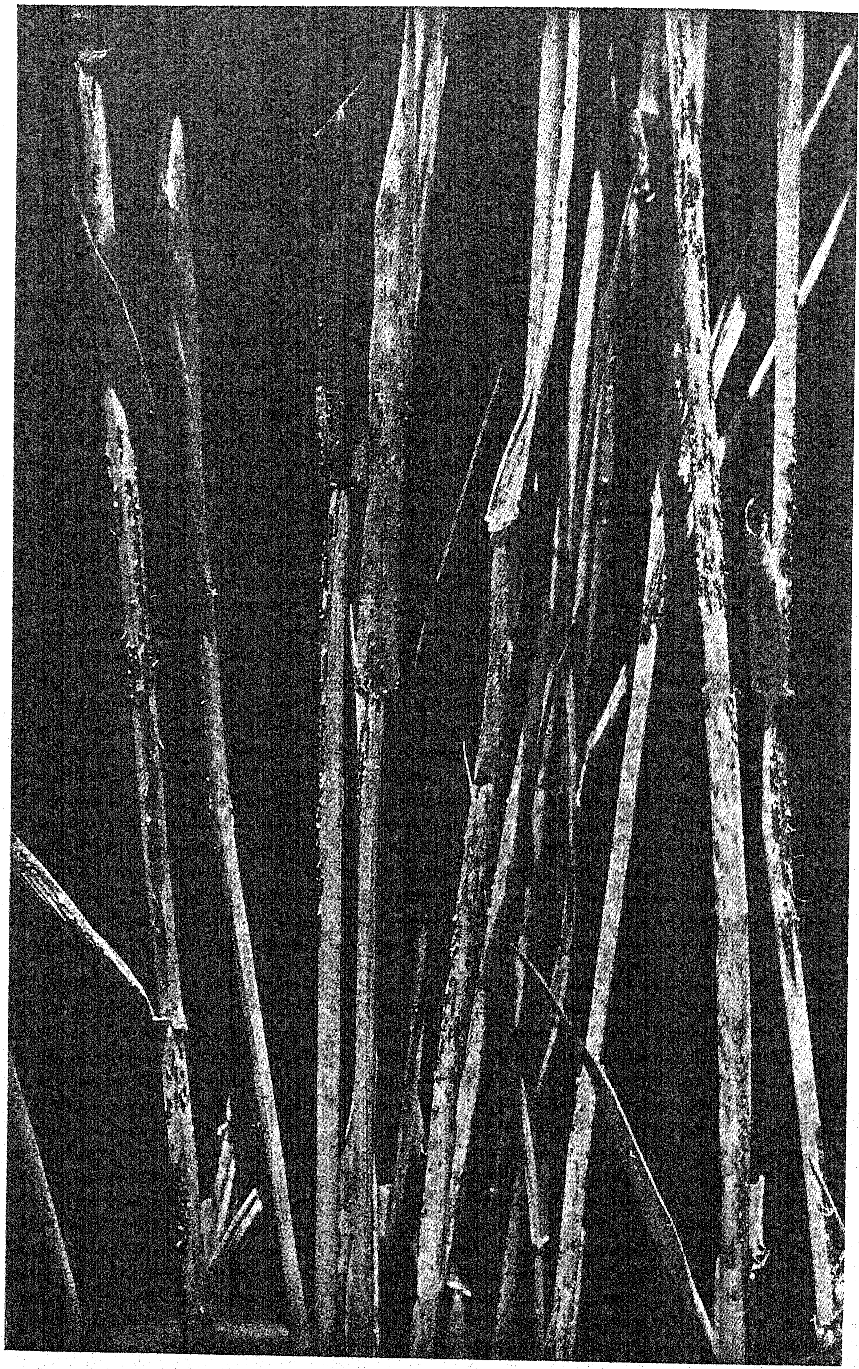

PLATE 69. Culms of wheat attacked by black rust (*Puccinia graminis tritici*)

reaction to important cereal rusts and natural infection in most of the countries, viz., the U.S.A., Canada and Australia.

In India, Butler (1918), and Butler and Bisby recorded the occurrence of *Puccinia graminis* on *Brachypodium sylvaticum*, *Festuca gigantea* and *Festuca kashmiriana* in the Himalayas but did not mention anything about their 'specialized forms'. Later Mehta (1933, 1940) demonstrated by cross-inoculation experiments that *Bromus patulus* and *Brachypodium sylvaticum* and possibly *Avena fatua* were collateral hosts of *Puccinia graminis tritici*. He could not, however, get any evidence to demonstrate that these grasses help in the oversummering of the rust. Prasada (1948b) recorded the occurrence of *Puccinia graminis* on *Bromus patulus*, *Agropyron semicostatum*, *A. longiaristatum* and *Poa nemoralis* near Simla Hills and proved, on the basis of cross-inoculation experiments, that the black rust from *Bromus* only was *Puccinia graminis* var. *tritici*. He also recorded that *Puccinia glumarum* occurring on *Agropyron semicostatum* and *Phalaris minor* cannot infect wheat or barley.

Prasada (1948b) and Vasudeva *et al.* (1953) have shown that under glass-house conditions a large number of grass species are susceptible to one or the other rusts of wheat. Prasada (1951) also recorded the occurrence of *P. graminis tritici* on 12 exotic grass species (namely, *Bromus coloratus*, *B. carinatus*, *B. mallis*, *Hordeum distichum*, *H. murinum*, *H. stenostachys*, *Agropyron semicostatum*, *Lolium perenne*, *Hilaria jamesii*, *Aegilops squarrosa*, *Ae. ventricosa* and *Ae. triuncialis*) in the experimental plots of the Indian Agricultural Research Institute. Existence of natural infection of yellow rust on *Bromus catharticus*, *B. japonicus* and *Hordeum murinum* at Delhi was also recorded by Vasudeva *et al.* (1953). However, there is no conclusive evidence to prove that grasses are playing any part in the annual recurrence of the rusts either in the hills or the plains of India. *Briza minor* and *Vulpia myuros*, reported to be collateral hosts of black rust, have actually been found to harbour the oat rust, *Puccinia graminis avenae*. It is very likely that in the Nilgiri and Palni hills these grasses help in the oversummering of the black rust of oats. In glass-house tests, *Briza minor* was found to be immune to all the races of black rust of wheat but on *Vulpia myuros* small resistant type of pustules appeared only with some races of black rust, there being no infection with the others. How far such a grass can play any significant part in the perpetuation of the disease under natural conditions is not quite clear. In this connection it is worth mentioning that a number of black rust samples from this grass have been analysed and only races of oats rust were recovered. No definite information is yet available regarding the rôle of grasses in the perpetuation of the disease in India. Introduction of exotic varieties of grasses is, therefore, fraught with considerable risk. If some of these susceptible varieties get naturalized in the hills, where rusts survive during the critical period, they may play a significant part in the perpetuation of the disease and complicate the problem all the more. It is, therefore, essential that all the newly introduced grass varieties should be properly screened for their resistance to rusts of wheat and barley before their release for general cultivation in the hills (Prasada, 1951; Vasudeva *et al.*, 1953).

Physiologic specialization. The concept of physiologic races in rusts arose when it was demonstrated that 'forma specialis' could further be divided into different forms. Stakman and Levine (1922) selected 12 varieties of wheat, after screening a large number, for the identification of races of black rust. This set of differentials is being extensively used practically all over the world for the identification and isolation of races. On the basis of reactions of these differentials to rust samples, more than 250 races of *P. graminis tritici* have been isolated from different parts of the world (Stakman and Harrar, 1957). For the identification of races of brown and yellow rusts of wheat, the differential varieties selected by Jackson and Mains (1926), and Gassner and Straib (1932, 1934) have been used in this country.

A sound knowledge of the existence of all the physiologic races of a particular rust, prevalent in a region, is of fundamental importance before any effective programme of breeding for resistance can be undertaken. In this country the work on the study of physiologic races of different rusts of wheat was initiated by Mehta in 1931 and up to 1933 he recorded the existence of four races of black (i.e., races 15, 40, 42 and 75) and two of brown rust (10 and 63). Later, in 1940, he recorded the presence of six races each of black and brown rusts and eight of yellow rust. During the subsequent five years seven more races of all the three rusts of wheat were recorded by Prasada and Lele (1952). A consolidated account of the prevalence and distribution of races from 1932 to 1952 was given by Vasudeva *et al.* (1955).

Existence of two biotypes of race 42 and one of race 15 was recorded by Uppal and Gokhale (1947), and Gokhale (1950) respectively. In 1956, Prasada and Sreekantiah recorded the occurrence of a new biotype in race 21 of *Puccinia graminis tritici.*

Till 1958 (Vasudeva and Joshi, 1958) the following races and biotypes of the rusts had been isolated in this country :

Black rust : 15, 15-C, 17, 21, 21-A, 24, 34, 40, 42, 42-A 42-B, 72, 75, 117, 122 and 194.
Brown rust : 10, 11,17, 20, 26, 63, 70, 77, 106, 107, 108 and 162.
Yellow rust : 13, 19, 20, 31, A, D, E, F, G and H.

From the data available, it is clear that the races in the Indian sub-continent have not remained constant and the position has changed considerably since the work was initiated in 1930. During the last 25 years the frequency of some of the races has shown considerable fluctuations. An outstanding example of such a change is in the frequency of races 15 and 21 of black rust (Vasudeva *et al.*, 1953). Race 21, which was 'exceedingly rare' (Mehta, 1940) up to 1942, gradually became the most prevalent race and now it is considered to be the most widely distributed one. On the other hand, race 15, which was one of the first recorded races and was widely prevalent earlier (Mehta, 1933), has gradually dwindled and is now practically absent. Such shifts of population are not rare and have been recorded from many other countries as well. Biotype 15-B in the United States was isolated in 1939 and it remained a rare race for more than a decade; however, since 1951 it has spread in many parts and has taken a heavy toll in 1950–51, 1953 and 1954, particularly of *durum* wheats. The unexpected rise in the frequency of this race can be judged by the fact that it was met with in 63 per cent uredial isolates in 1953 as against only 0·1 per cent in 1949.

Such changes in racial population have also been recorded from Canada (Newton and Johnson, 1946), Australia (Watson and Waterhouse, 1949), Mexico (Gibler *et al.*, 1953), etc. The precise reasons for such fluctuations are not well understood, but it appears that a combined effect of a large number of ecological factors

(Loegering, 1951) and the changes in varietal position might be the chief factors which bring about such a change in the racial composition from time to time.

Besides such shifts of populations, the appearance of new races is a factor of great importance in breeding for resistance. As has already been stated earlier, there has been a gradual increase in the number of races of black and brown rusts of wheat, though in case of yellow rust the position is unchanged for nearly the last 15 years. It is quite possible that some of these races did exist earlier but escaped detection due to their restricted distribution. Another possibility of the appearance of new races is by mutations in already existing races. Mutations in rusts is comparatively a rare phenomenon and the appearance of new races by mutations has been reported only by a few workers such as Stakman *et al.* (1930), D'Oliveira (1937), and Watson and Waterhouse (1949). In this country, however, no mutations of any race involving changes in pathogenicity have been observed even though some of the races have been maintained for more than 400 uredial generations. Cases of colour mutation have been reported in races 15-C and 194 of black rust by Misra and Lele (1955), and Joshi and Kak (1955) respectively. The third possibility is through actual hybridization on *Berberis* in some remote parts of the mountainous regions of the country. Taking into consideration the susceptibility of certain indigenous species of *Berberis* like *B. lycium* and also the possibility of the occurrence of *B. vulgaris* in the interior of the hills, the chances of appearance of new races due to hybridization cannot be ruled out altogether (Vasudeva, 1954). However, there is no experimental data to support this view. How far the introduction of new races, particularly by aerial communications, is possible is again an open question. Yet another possibility of the appearance of new races is due to heterocaryosis or parasexuality. Nelson *et al.* (1955) recorded the appearance of a virulent heterocaryon from a mixture of biotypes of races 38 and 56 of black rust. The heterocaryon later became unstable after a number of uredial generations. The authors have concluded that probably heterocaryotic biotypes are produced in nature also. Watson (1957) and Bridgman (1959) obtained new races by mixing uredospores of two known races and suggested that it might be due to some sort of somatic hybridization. Watson feels that new races are coming up in Australia by some such process.

Control measures. With the present knowledge of the annual recurrence of rusts in India, where perpetuation takes place through the agency of oversummering uredospores in the hills of India, Mehta (1950) suggested that rust epidemics could be controlled to a considerable extent by eliminating the inoculum at the source. To achieve this he has suggested, as a short-term measure, the eradication of out-of-season wheat and barley plants in the hills, replacement of wheat and barley cultivation by that of oats, and suspension of summer crop in Nilgiri and Palni hills by legislation. He also advocated the breeding of resistant varieties suitable for cultivation in the hills for that very purpose.

As pointed out by Chester (1946), " Adjustment of the time of sowing, fertilization, destruction of volunteer cereal plants, application of fungicides—these are but adjuncts to the fundamental solution of the cereal rust problem: the breeding of cereal varieties that are resistant to rust, the most certain and effective, and the most economical means of checking the ravages of the cereal rusts ".

SMUTS AND BUNTS

Loose smut of wheat [*Ustilago nuda* (**Jens.**) **Rostrup.**]. Loose smut of wheat is characterized by the appearance of black sooty ears instead of normal ears filled with grains (Plates 70, 71). It is a widespread disease though usually it does not cause more than 2 to 3 per cent loss but at times, in certain regions, it causes considerable damage to the crop. It has been reported from almost all parts of the world where wheat is cultivated. It is not an important disease in Britain but in certain areas of the United States it is regarded as a serious one. It has been estimated that in Pakistan it brings about a loss of Rs. 13 million annually. In India, exact loss caused by this disease has not been estimated but it is regarded to be one of the major diseases of the wheat crop.

The infected plants cannot be differentiated from healthy ones till the heading stage is reached. The smutted spikes emerge earlier than the normal ones and release a powdery mass of black chlamydospores. The smutted head consists of deformed spikelets. A thin fragile membrane covers the powdery mass; this is usually damaged before the emergence of the diseased ear. In the infected ear all the floral parts including the glumes and sometimes even awns are replaced by spore masses. Partially smutted ears, with lower parts affected and upper parts free, have also been recorded. The spores are readily carried by wind to the other healthy ears, where they cause fresh infection. Rain and wind wash away or remove the spores, leaving the naked rachis behind. In a severely infected plot the diseased plants are easily spotted out from some distance. In dry weather the spores are disseminated by wind and at times they appear as faint clouds over the fields. They settle down on the stigma and cause fresh infection. Usually the entire stool is affected but sometimes a few healthy ears in the clump can be seen amidst the affected ears. Loose smut of wheat is mainly a disease of the ear but in case of severe infection spore formation may occur on the leaves or very rarely on the stem also.

Internal symptoms: Different varieties of wheat exhibit different degrees of invasion in the various parts of the seed. Usually the dormant mycelium remains in the embryo but at times it spreads to the primordia of the roots. With the growth of the seedling, the dormant mycelium also grows and keeps pace with the growing tip. Some workers have recorded a slight hypertrophy of the tissues of vascular bundles within the cellular spaces. It has been also recorded that in the wheat varieties Hope and Presta the smut-infected wheat grains have a distinct greyish-purple colour. It may, however, be mentioned that such cases are perhaps exceptions and so in general there is no external symptom which may help in distinguishing a healthy plant from a diseased one before emergence of the head.

Physiologic specialization. In the first study of the physiologic specialization in *U. tritici*, Piekenbrock (1927) recorded the existence of two races. Later on, by using more varieties and getting more collections from other places Grevel (1930) recognized the presence of four races. Moore (1936) isolated five races on the basis of a study of 12 collections. Radulescu (1935) did not get any indication of physiologic specialization amongst seven collections of loose smut of winter wheat in Rumania while he could isolate three races from the collections made from spring wheat. These reports show that there exists a narrow range of specialization in this species. Bever (1947) conducted similar tests using 10 tester varieties against 52 collections and recorded the occurrence of 11 races in the soft-wheat regions of the U.S.A. Sometimes, a particular race appears to be specialized to a certain variety group. In China, six collections of loose smut of wheat from *Triticum turgidum* represented a race which was apparently specialized on this group while eight other collections were specialized to common wheat group (Wang, 1946). The analysis of six smut collections made by Hanna (1947) has given good evidence to indicate that three physiologic races of the pathogen occur in India.

Methods of control. Seed certification for the control of the disease may be regarded as one of the promising methods to reduce the losses caused by the fungus. This method ensures the supply of healthy seeds only. In the eastern zone of Germany certification of elite barley or wheat seed crop is refused if there is a single plant infected by loose smut within a distance of 100 paces on either side. It is also refused if there is an infected field at a distance of less than 50 m. in the direction of prevailing winds (Kublan, 1952).

Roguing of infected varieties from the fields can also be helpful in decreasing the incidence of the disease.

Another method for controlling the disease is by hot-water treatment. This method was developed by Jensen in 1888. In short, the method consists of soaking the seed in cold water for four to six hours to activate the internal mycelium and subsequently immersing in hot water at 129°F (54°C) in a water bath for ten minutes. The treated seed is then dried to avoid attack of moulds and rotting of the seed in storage. This method, though quite successful in controlling the disease, has certain limitations. The treated cracked seeds get injured. Besides, the method is tedious and slight rise in temperature above the limit mentioned is likely to damage the embryo.

This method has been modified by several workers and the use of chemicals for soaking the seeds has been found to be effective. Soaking the seed in potassium iodide (Hanna and Popp, 1935) or Spergon (Tyner, 1951, 1952, 1953) is reported to give significant control of the disease.

Another method which is quite inexpensive and easy to follow is solar heat treatment (Luthra, 1932, 1953a,b). It has been reported to be successful in north-western India. In this method, solar heat is utilized for the destruction of the fungus instead of hot water. The treatment of the seed is usually done in the months of May and June on a dry day when the shade temperature is expected to reach 120°F.

The seed, for treatment, is soaked in water for four hours (usually from 8 A.M. to 12 noon) and then spread on a cloth sheet in a thin layer from noon to 4 P.M. The well-dried seed is then stored for next sowing. The following precautions are required to be taken for the success of this method.

1. The treatment is to be done when shade temperature is more than 120°F.
2. The operation is to be carried out in a bright cloudless day with the least disturbance in the air.
3. The treated seeds should be dried properly before storage.

This treatment has been found effective only in areas where summer temperature is very high.

Breeding for resistant strains is another method of control of the disease and for the farmer this is the cheapest and the most convenient one. The varieties of wheat show a differential response to different races of the fungus. Tests for selecting resistant varieties have been carried out in many parts of the world, such as the U.S.A. (Tapke, 1929; Atkins, 1943; Atkins *et al.*, 1947), China (Yin, 1948) and Australia (Pugsley, 1943). In India, Mundkur and Pal (1941), and Pal and Mundkur (1945) tested more than two hundred varieties and found a number of them either immune or highly resistant to the smut. These included the then important varieties, N.P. 114, N.P. 120 and N.P. 165. Since that time many other varieties, like N.P. 710, 718, 770, 797, 798, 799 and 809, have also been found to be highly resistant.

Very recently, the promising strains N.P. 823, 824 and 827 characterized by a high degree of resistance have been evolved at the Indian Agricultural Research Institute.

Bunt or stinking smut of wheat. It is one of the few diseases of wheat which attracted attention of the early workers. Tillet distinguished bunt from smut of wheat and also established the infective principle of bunt dust. The disease is sometimes called 'stinking smut' because of the pronounced disagreeable odour emitted by the infected grains. The disease has a world-wide distribution and it occurs practically in all parts of the world and in some is regarded as a major disease of the crop. It is more prevalent in the drier regions of the globe. In India, the disease is mainly restricted to the hilly regions of North-West India, being extremely common in Kashmir and the western Himalayas. Singh and Mathur (1953) recorded the presence of the disease from Garhwal, Almora and Nainital. It has also been reported from Kangra and Kulu valleys of the Punjab. So far, it has not been recorded from the eastern and the southern hills. It may, however, be mentioned here that Mundkur (1944) recorded the occurrence of *T. caries* and *T. foetida* on wheat at Delhi in 1941; this is apparently the first record of the disease from the plains of India.

In India, the disease (Plate 72) is caused by two distinct species of *Tilletia*. Of these, the smooth-spored species, *Tilletia foetida* (Wallr.) Liro, is mainly limited to altitudes above 3,500 ft. and the rough-spored one, *T. caries* (DC.) Tul., occurs at altitudes above 5,000 ft. in the hills. The third species, *T. controversa* Kuhn, which causes the dwarf bunt of wheat, has not yet been reported from India.

The losses caused by the disease are mainly due to the replacement of the grain content by smut spores. The grains emit a foul smell which reduce their market value. Grains from bunted fields are blackened and are, therefore, poor for milling as well as feed purposes. The harvesting and threshing by mechanical means of such infected crops present some difficulty. The presence of spores in large quantity can cause explosions in separators and fires in machines.

The losses caused by the disease have been worked out in many countries. In the U.S.A., Tisdale *et al.* (1927 a, b) estimated the loss in yield to be from 5,000,000 to 26,000,000 bushels per year. In Canada, grains worth Rs. 400,000 is lost due to bunt attack (Hanna and Popp, 1930). In India, Mitra (1935) reported 30 to 40 per cent loss of crop due to the disease in Jubbal in the Simla Hills. Singh and Mathur (1953) observed 1 to 10 per cent bunted grains in wheat samples from the Kumaon Hills of Uttar Pradesh. It is reported that the disease causes heavy damage, extending up to 50 per cent, to the crop during certain years in the Kangra and Kulu valleys of the Punjab.

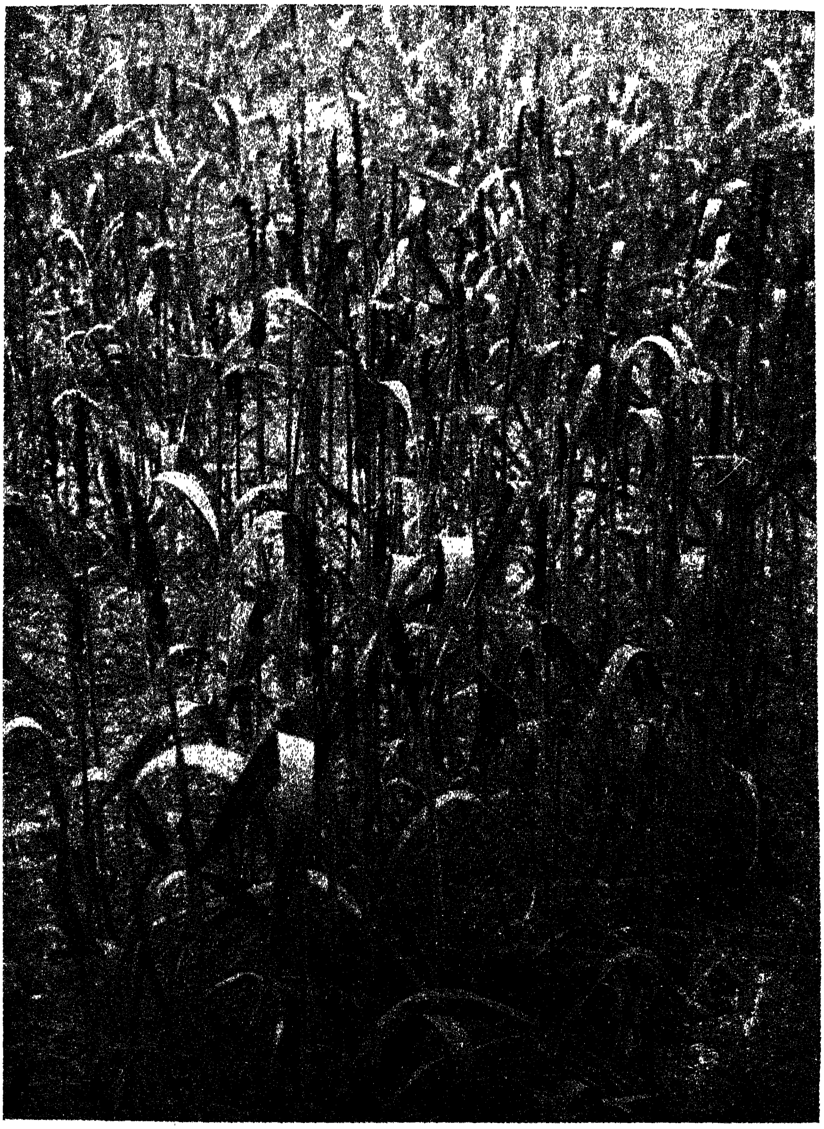

Plate 70. Wheat plants affected by loose smut (*Ustilago tritici*)

PLATE 71. Inoculation of wheat ears with loose smut spores

The symptoms of the disease do not usually become apparent until the emergence of the spike. Affected plants ripen more rapidly than the normal ones. It has, however, been reported that certain varieties when infected by bunts exhibit external symptoms such as dwarfing of the plants, small light-coloured spots on the leaves and a greyish cast of the foliage and culms during the period of tillering (Churchward, 1934; Holton and Rodenhiser, 1942). The root growth of bunted plants is depressed and the foliage reduced. According to Potter and Coons (1918), stunting effect is more pronounced in plants affected by *T. caries* than by *T. foetida*. Sometimes only a few shoots in the affected stool get the infection. Due to bunt infection the general shape of the spike is changed. The spikes are usually rigid, unlike the normally bent ones, dark to olive green with their palea and glumes wide open. In the case of bearded varieties the awns get deformed or they are not formed at all. The bunt-balls are united in a greasy mass which hardens on drying. The bunted grains may remain unbroken at harvest time but they get ruptured during threshing. Infected grains are also plump as compared to healthy ones (Plate 72) and emit the characteristic fishy smell which becomes more pronounced when the grains are crushed. The smell is due to the formation of trimethylamine.

Lang (1917) reported that the bunt-affected plants are rendered more susceptible to *Puccinia glumarum*. Thus, bunt attack affects the physiology of the host as well.

Soil temperatures and humidity are very important factors for infection by bunt spores. Heuser (1922) stated that the optimum temperature for infection of the wheat plant is 6°–10°C. The infection can take place between a soil temperature range of 5° to 20°C. High soil moisture content, i.e., 25 to 30 per cent, is apparently more conducive to infection by the fungus. Apart from these factors, the actual spore-load determines the intensity of the attack to a great extent (Lobik, 1926). Usually deep-planting, about two to three inches, of the seed, which apparently retards free development of the seedling, is also favourable for infection.

Many physiologic races, both in *T. caries* and *T. foetida*, are known. Determination of physiologic races is done mainly on the basis of their pathogenecity but apart from this certain morphological characters, such as size of spores and spore-balls, markings on the spores, their colour and length of the promycelium, are also taken into consideration.

The evidence of the existence of physiologic races was put forward by Faris in 1924 but the actual identifications of races was done by Rodenhiser and Stakman (1927). They identified two races in *T. caries* and three in *T. foetida*. Later, Holton and Rodenhiser (1942) recorded the existence of 14 races in *T. caries* and ten in *T. foetida*. In 1945, Rodenhiser and Holton recorded more races. Since the system of identification is not quite uniform, it is possible that some of the races reported as different might be the same.

In India, work on the physiologic races was started recently and so far eight races of *T. foetida* and seven of *T. caries* have been identified.

Control measures. Seed dressings have been recognized as effective methods to control the bunt for a long time. Kuhn, about 1860, recommended dipping of seed in copper sulphate solution and this remained an effective method for checking the disease for about half a century. One of the defects of the copper sulphate is that it causes seed injury.

Another fungicide which was in use for a long time is formalin. It is comparatively cheaper and has the additional advantage of ensuring protection against soil-borne infection. Handling of formalin is hazardous to the health of the worker and hence it is not now commonly used. Instead, copper carbonate, which is non-toxic to the seed, has been used by some people. In addition to this advantage, copper carbonate gives protection to the grains against storage grain pests.

Organic mercury compounds, like ethylmercury chloride (Ceresan), at the rate of 0·2 per cent of the seed weight or ethylmercury phosphate (New Improved Ceresan) applied at the rate of 0·05 per cent of seed weight have been claimed to be quite effective in checking the disease. At times, New Improved Ceresan is also injurious to the seed.

Another chemical compound which is being used in foreign countries at present is hexachlorobenzene (HCB), since HCB preparations are quite effective against soil-borne infection. Another advantage of these is that they are non-poisonous.

Shallow sowing, preferably in dry rather than moist soil, is considered as a method of checking the disease with considerable success. Early sowing in the month of October, when temperature and moisture factors are unfavourable for spore germination and infection allows seedlings to develop beyond the susceptible stage ahead of the infection and thus escape the disease attack.

Introduction of clean seeds and rotation of crops are also regarded good methods for the control of the bunts.

Breeding of resistant strains is useful for control of the disease.

Karnal bunt of wheat. Karnal bunt or Partial bunt [*Neovossia indica* (Mitra) Mundkur] occurs commonly in submontane districts of the Punjab, Delhi and western Uttar Pradesh. It is known to appear in an epidemic form in certain years causing serious losses in yield and quality of the grain. The disease is endemic to this country and has not yet been fully investigated. It has been demonstrated that unlike other common bunts of this crop, the disease is air-borne and that is why, generally, only a few grains in an ear are infected and, hence the name partial bunt.

The characteristic feature is that the infection is only in very few ears and even in the same ear only few grains are infected. The diseased plants cannot be differentiated from the healthy ones till the grains have formed. Completely infected ears are met with very rarely (Mitra, 1937). Normally, only one to five spikelets show bunted grains in an ear while the remaining grains remain normal and healthy. In the case of unripe ears it is rather difficult to detect the presence of infected grains as they remain completely covered by the glumes, but in the mature ears the glumes open out, exposing the grain; in the early stages only a black spot appears at the tip of the grain. In badly attacked spikelets the glumes spread apart and finally drop off exposing the bunted grains. The grains also fall to the ground with the slightest disturbance. A peculiar smell of rotting fish is emitted by the infected grains. This is more pronounced if the grains are crushed.

The infection does not usually destroy the embryo since it spreads to the tissue along the groove, leaving the smooth side of the seed unaffected. The germination of the grain is not significantly reduced. Plants raised from infected grains, however, show reduction in the length of ears and number of spikelets.

The spores appear dark in mass but singly they are dark brown in colour, spherical or sub-spherical to oval measuring $22\text{–}44\mu \times 25\text{–}55\mu$ in diameter with an average of $32\mu \times 40\mu$. The episporc is reticulate with the ridges or scales projecting. Amongst the spores are some relatively thin-walled sterile ones, which are round or pear-shaped and smaller in size. These represent undeveloped spores.

The fungus perpetuates itself through the chlamydospores (spores or teleutospores), which are either blown about by the wind and fall to the ground or are carried to the soil with the diseased seed. These teleutospores are resistant bodies and remain viable in the soil for three to four years. The teleutospores germinate during February–March when conditions for their germination are favourable and which coincides with the flowering period of the crop. The sporidia fall on the flowers and germinate to produce infection hyphae, which soon attack the developing ovary and transform the starch into a mass of bunt spores. This type of infection, which is brought about by the air-borne sporidia, was first proved experimentally by Ramamoorty and Mundkur (1944) and later corroborated by Bedi *et al.* (1949). Mild temperatures, cloudy weather and light showers of rain are helpful for infection and development of the disease.

Since the disease inoculum lies in the soil, direct control of the disease is rather difficult. Fungicidal seed dressing will have limited value, though it will result in reducing the disease inoculum which enters the soil through this means. Breeding of resistant varieties is the chief practical means of control. Work on the biology of this organism and breeding of disease-resistant varieties is in progress at the Indian Agricultural Research Institute.

Flag smut of wheat. Flag smut of wheat is caused by *Urocystis tritici* Koern. It has a world-wide distribution, but is not considered to be of major importance except in some countries. In some parts of the world it has been controlled to a considerable extent, primarily due to the cultivation of resistant varieties. Noble (1937) reported that, in New South Wales, it has ceased to be regarded as a serious disease as it was considered to be before the cultivation of resistant varieties. In the United States of America the disease was reported in 1919 and has since then appeared only in scattered regions. Even from these regions it has been practically eliminated by using resistant varieties.

In India, the disease was first noticed in 1906 at Lyallpur by Butler (1918). Usually the incidence of the disease is not more than 5 per cent, but at times it is up to 60–70 per cent in individual fields in certain parts of the Punjab and Delhi. It is absent in Uttar Pradesh, Madhya Bharat and Bihar.

The first symptom of the disease appears in the leaf blade of the flag leaf in the form of swollen lines running parallel to the veins. In early stages the sori are grey but they turn black later. The lines or the linear sori are covered by the epidermis in the early stages. The epidermis, however, does not remain intact for a long time. A black powdery mass of spores is released by the rupture of the epidermis. The affected leaves assume a drooping form and gradually wither away. The plants affected by the disease remain stunted. The dwarfing is the result of reduction in the elongation of the internodes. Culms get twisted giving plants a distorted appearance (Plate 73). In case of susceptible varieties, usually every shoot is affected. The number of tillers is also reduced considerably. Usually infected plants fail to produce ears and, even if ears are formed, the grains are shrivelled and usually not viable.

The spores of *Urocystis tritici* can remain viable in the soil and retain their infectivity for about three years under natural conditions. The spores are carried along with debris. They have been found to remain viable even after passing through the alimentary canal of animals, as well as in the compost manure prepared from infected plant tissues. All these comprise sources of infection to the newly sown crop. Another method of perpetuation of the disease is through contaminated seeds. At the time of threshing and winnowing the spores get attached to healthy grains and infect the seedlings at the time of germination.

The disease is, therefore, both externally seed-borne and soil-borne. As the spores have long viability they can persist in a particular area for a long time and are greatly influenced by soil temperature and soil moisture.

Cultural methods, such as shallow depth of sowing and adjusting the time of first irrigation, have been found to reduce the infection. Early sowing, when the temperature and humidity are unfavourable for spore germination, permits the seedlings to escape infection. Hafiz (1948) recorded that early sowing of wheat at a temperature of about 28°C reduces the incidence of flag smut to a minimum.

In Egypt, it has been shown that if plants are irrigated immediately after seedling emergence the incidence was less as compared to those fields where the soil had been irrigated previously. Deep sowing also promotes flag smut development and, hence, shallow sowings might help in reducing the incidence of the disease.

Seed-dressing fungicides effectively control the seed-borne infection. Copper carbonate was the first dry fungicide used in wheat bunt control and was also successfully used against flag smut of wheat. Cultivation of resistant varieties, however, appears to be the most effective method for controlling the disease and, as already mentioned, the practice of cultivation of resistant varieties has actually reduced the incidence of the disease in Australia and America. Tisdale *et al.* (1923, 1927a,b) observed that red winter wheat types were immune in the U.S.A. Verwoerd (1929) recorded the existence of 18 varieties out of a total of 48 tested varieties which were either immune, highly resistant or resistant to flag smut. Pal and Mundkur (1941) found that out of 97 varieties tested six varieties were resistant and two were highly resistant.

POWDERY MILDEW

The disease is caused by *Erysiphe graminis tritici* (DC.) E. P. Marchal. In many parts of the world powdery mildew is regarded as a destructive disease. In certain parts of Ohio it causes more damage than the rusts. In severe cases of infection, as was reported in Canada in 1932, the incidence was 80 per cent and the ears were only half filled. Vik in 1937 reported that in Norway the damage due to powdery mildew attack in spring wheat causes considerable reduction in the yield. Similar cases have been reported from Prairie Province of Canada (Cherewick, 1944).

Mildew caused by *Erysiphe graminis* (DC.) has a wide host range and it has been recorded on many cereals and grasses. Specialized forms of the fungus attack wheat, barley, oats, *Bromus* and *Poa*.

In India, the disease is not very important as it occurs mainly in the hills where the area is limited; accurate data regarding the loss caused by it are not available. The disease appears only sporadically in the foothills and plains (Mehta, 1929; Arya and Ghemawat, 1953). The disease has also been observed in the experimental fields

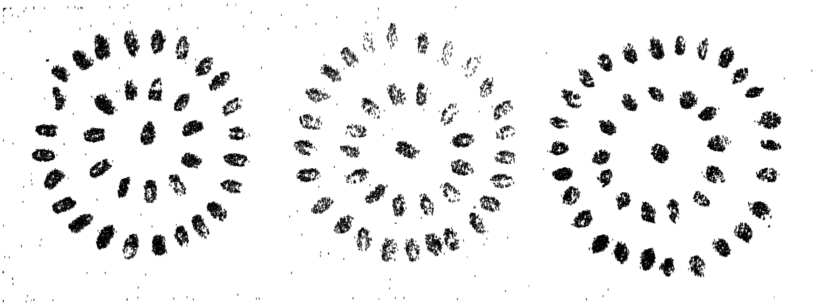

PLATE 72. Healthy grains of wheat (centre) compared with grains affected by hill bunt (*Tilletia foetida* and *T. caries*) (Left) and by Karnal bunt (*Neovossia indica*) (Right)

PLATE 73. Plants affected by flag smut of wheat (*Urocystis tritici*)

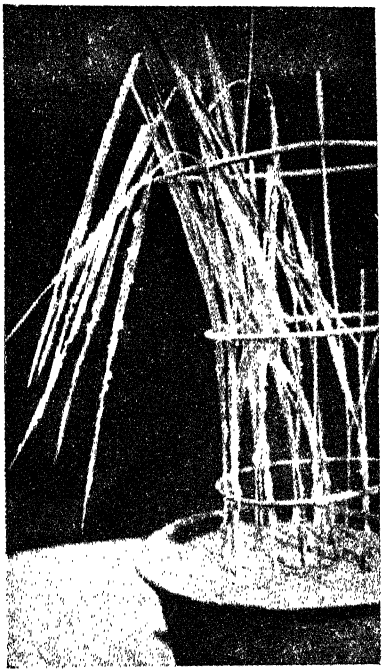

PLATE 74. Plants affected by powdery mildew of wheat (*Erysiphe graminis tritici*)

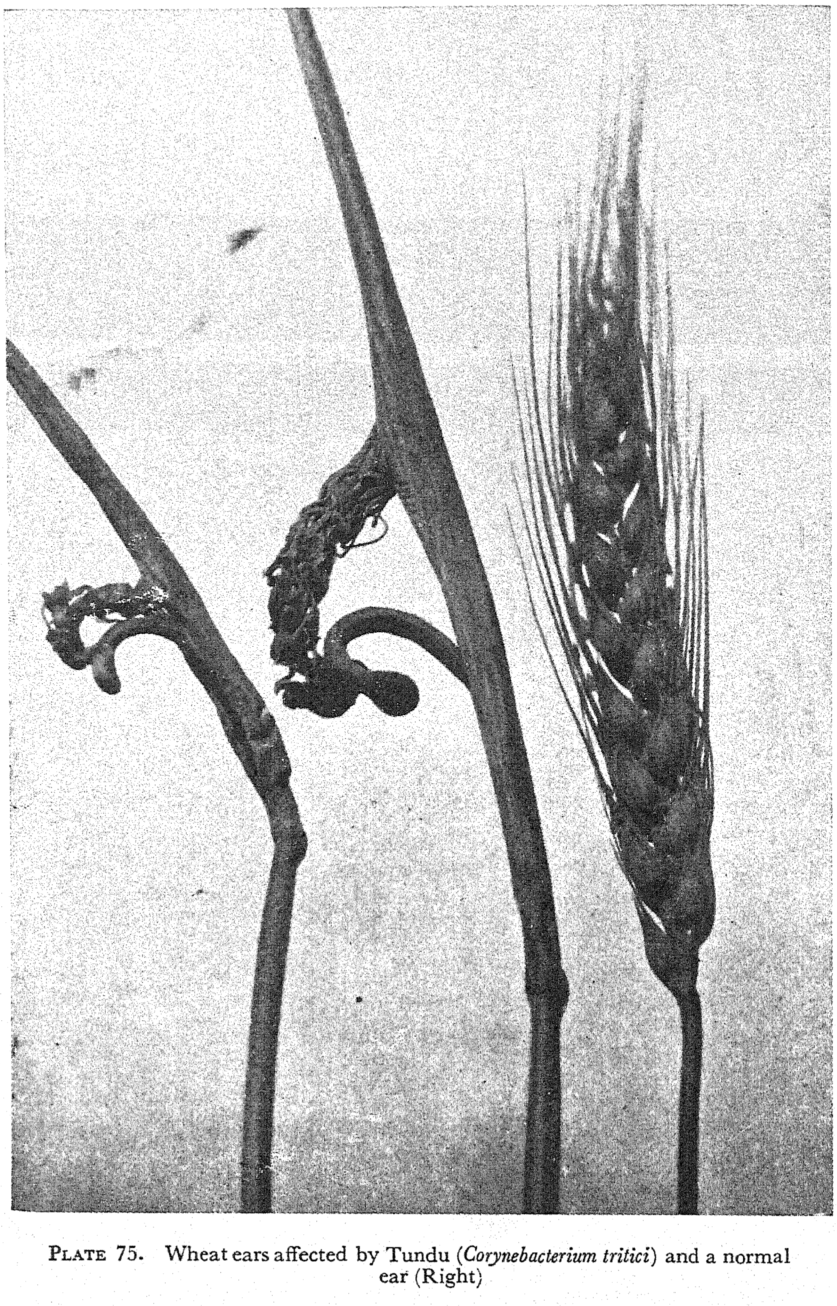

Plate 75. Wheat ears affected by Tundu (*Corynebacterium tritici*) and a normal ear (Right)

of the Indian Agricultural Research Institute. The perithecial stage has been reported in the hills by Mehta and near Jodhpur by Arya and Ghemawat.

Infection appears as a superficial greyish-white mass on the leaves, stem and sheath (Plate 74). Usually the attacked plants do not die though in cases of severe attack the seedlings may collapse at times. The white powdery patches on the infected areas later turn brownish and are studded with dot-like perithecia, resulting in the premature drying of the leaf. The fungus usually develops on the upper surface of the leaf. Infected leaves are crinkled, twisted or otherwise deformed. At times the development of ears may be checked partially or wholly.

The first report of the existence of different forms in the fungus was recorded by Marchal (1902); he distinguished the existence of seven forms. Salmon (1903) in Europe and Reed (1905) in the U.S.A. demonstrated the extreme specialization in this fungus. Occurrence of physiologic races within *Erysiphe graminis tritici* was demonstrated by Mains in 1933 and he established the presence of two races by using varieties Axminister, Chul, Auron and Norka as differentials. Since his discovery existence of races has been recorded from many parts of the world. Lowther (1950) used another set of differentials, viz., Axminister, Ulka, Chul, Hope and Normandie and differentiated ten races in south-eastern United States of America.

In India, extensive work on the identification of physiologic races has not been undertaken, but preliminary investigations carried out at the Indian Agricultural Research Institute indicate the existence of at least two such races (Prabhu, 1959).

According to Mehta (1929), the annual recurrence at the foothills and plains is through wind-blown conidia from the hills, where the conidia seem to survive in summer months. Arya and Ghemawat (1953) have also come to similar conclusions and felt that possibly Mt. Abu in Rajasthan might be playing an important part in the annual recurrence of the disease in the neighbourhood of Jodhpur.

Control measures. The disease can be controlled quite effectively by the use of sulphur dust. Use of sodium thiosulphate (1 per cent solution in water) has also been found effective in reducing the intensity of attack. These methods of control, however, are not economical and hence cannot be recommended on a field scale. Development of resistant varieties, therefore, appears to be the most practical method of control of the disease.

LEAF BLOTCH

Speckled leaf blotch. The speckled leaf blotch of wheat is caused by *Septoria tritici* Desm. It has a wide distribution in Europe, Asia, Australia and America. The fungus was first described by Desmazieres in 1842 (Luthra *et al.*, 1938) as *Septoria tritici*. Later in 1845 another species of *Septoria* occurring on grasses and differing from the above-mentioned species in having smaller pycnidia was also reported by him and was identified as *S. graminum*. Weber (1922 a, b) concluded that the form on wheat was not different from *Septoria graminum* and that the appropriate name of the fungus should be *S. tritici*.

In India, it is of common occurrence in the Punjab and other northern areas, but is rather rare in the South.

Symptoms. The first symptom of the infection is slight mottling, barely noticeable in the early stages. Gradually it becomes conspicuous forming circular to irregular scatterd spots on the leaf surface, the colour changes and the lesions become blackish due to the formation of pycnidia. Heavily infected leaves which are studded with pycnidia die prematurely. The newly formed leaves also get infected. In severe cases of infection, the disease spreads to leaf sheaths producing similar symptoms. At times the lesions appear on the awns and stem as well but definite spots are not formed on them. In such cases only pycnidia appear. Usually the infected plants do not die out but severely infected young plants dry up at times. The grains produced by *Septoria*-infected plants are shrivelled.

The development of the disease is dependent on weather conditions (Luthra *et al.*, 1938). In the Punjab the disease can be noticed even in the last week of December if there have been showers of rain in the beginning of the month. Otherwise, it usually appears in the end of February or beginning of March. If the disease appears early the infected leaves die out but in case it appears late in the season the leaves show only partial drying up. With the rise of temperature in the beginning of summer the disease becomes considerably restricted.

It has been demonstrated by Luthra *et al.* (1938) that the pycnidia borne on diseased straw remain viable throughout the summer months. The disease is, therefore, carried over to the next crop through the pycnidiospores from the wheat straw stacked as chaff (*bhusa*). The fungus also remains viable in the diseased leaves left over in the field along with debris and the pycnidiospores from these leaves form a source of infection to the subsequent crop.

Control measures. On the basis of the above findings Luthra *et al.* (1938) have recommended the following control measures.

1. While giving the first ploughing to the field after harvest, the diseased plant debris may be buried deep in the soil.
2. The straw or *bhusa* should not be stacked in or near the fields where wheat is sown. All other precautions may be taken to prevent it from reaching the wheat fields.
3. Growing of relatively resistant varieties is beneficial. According to them, *durum* wheats are almost immune and *vulgare* wheats are susceptible to the disease.

Another disease of wheat which is closely allied to *Septoria tritici* is known as Glume Blotch and is caused by *S. nodorum* Bark. This disease has also been reported from Europe, America and Australia. In India, the disease was first recorded by Chona and Munjal in 1952 from South India. It is mainly restricted to the glumes and the disease manifests itself on the glumes as purple-brown or brown coloured, oval to elliptical spots varying from four to nine millimeters in length and two to three millimeters in breadth. Sometimes a yellowish halo encircles the lesions. At the later stages, due to the formation of pycnidial fructifications the lesions get studded by black dots. In rare cases, the infection spreads to leaves, leaf sheaths and even rachis.

The disease has so far been extremely restricted and at present it is considered to be of minor importance only. The life-cycle has been worked out abroad but not in India. It is very similar to that of speckled leaf blotch.

HELMINTHOSPORIUM DISEASES

Several species of *Helminthosporium**, such as *H. sativum* Pammel, King and Bakke, *H. tritici* P. Henn., *H. tritici vulgaris* Nisikado and *H. gramineum* Rabenh. ex Schlecht., have been recorded on wheat from various parts of the world. In India, *H. sativum* has been recorded on wheat from different regions of the country. Mitra (1931) recorded the occurrence of *H. bicolor* Mitra and *H. halodes* Drechs. var. *tritici* Mitra on wheat from Bihar. Another species resembling *H. sativum* in external symptoms but different in morphological characters was also recorded by Mitra on the leaf sheaths of wheat from Pusa. This species agrees closely with *H. tritici-repentis* Died. Patel *et al.* (1953) described a new variety, viz., *H. nodulosum* var. *tritici* on wheat from Bombay State.

H. sativum, under Indian conditions, is known to cause both leaf-spot and foot-rot disease. The foot-rot phase of the fungus is more commonly met with in some parts of the country. It results in the partial failure and stunting of the crop. The leaf spots are of dark brown colour and show the characteristic yellow rings coalescing to form long linear lesions. All the vegetative parts of the plant may be affected; the lesions are not always confined to leaves but may also be found on glumes as well. The central region of the spot is greyish-brown and bears conidiophores.

The leaf spots show considerable variation in size. The margins of individual lesions are definite and clear. They are usually oval to oblong and uniformly dark brown in colour. Under conditions favourable for infection the disease is capable of causing considerable damage. It has been reported by Sallans (1940) that under certain conditions, which are unfavourable for the development of pathogen, the plants can recover.

The root-rot or foot-rot disease is not caused by the species of *Helminthosporium* alone. Quite often other fungi, such as *Fusarium* and *Pythium*, are also associated. It is of common occurrence in the Punjab, Rajasthan, Delhi, Madhya Pradesh and Bombay states. It usually occurs in those areas where the temperature at sowing time is high and moisture content is low. Seedlings get attacked soon after emergence. McRae (1922) reported that the foot-rot disease of wheat caused considerable losses in Dharwar district and Central Provinces (now known as Madhya Pradesh). A species of *Helminthosporium* isolated from both places could kill the artificially inoculated seedlings.

Seedling blight is characterized by a dry rot type of tissue necrosis. Black or dark brown lesions appear on coleoptiles immediately after emergence of the seedlings. In severe cases the seedlings are killed before emergence or immediately afterwards. The lesions are prominent near the soil line from where they extend upward to the leaf blade. The plants get stunted and show more of tillering. The rot develops at or below the soil surface.

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*The nomenclature of *Helminthosporium* (original and acceptable name: *Helmisporium*) species on cereals has recently been revised by Shoemaker (1959, *Canad. J. Bot.* **37**) and the acceptable names for the *Helminthosporium* spp. mentioned here are : *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoemaker (=*Helminthosporium sativum* P. K. & B.); *Bipolaris bicolor* (Mitra) Shoemaker (=*Helminthosporium bicolor* Mitra); *Bipolaris halodes* (Drechsler) Shoemaker (=*Helminthosporium halodes* Drechsler; *H. halodes* Drechsler var. *tritici* Mitra; *Helminthosporium nodulosum* Berk. & Curt. var. *tritici* Patel, Kamat and Padhye); *Drechelera tritici vulgaris* (Nisikado)Ito(=*Helminthosporium tritici vulgaris* Nisikado); *Drechelera graminea* (Rabh. ex Schlecht.) Shoemaker (=*Helminthosporium gramineum* Rabh. ex Schlecht.); *Drechelera tritici repentis* (Died.) Shoemaker (=*Helminthosporium tritici* Died.).

Leaf spot. *Helminthosporium sativum* and *H. tritici-repentis* do considerable damage to the wheat crop in Pusa, Bihar (Mitra, 1934). The disease usually appears in the early stages of seedling growth and the first symptoms are the formation of yellowish, oval or oblong spots on the leaves and leaf sheaths. With maturity the spots change in colour and become dark brown. They have no definite shape and vary from oval to fusiform or even become irregular due to coalescence of several spots. The conidiophores are borne in the central greyish-brown region of the leaf or leaf sheath. The spots caused by both these species are more or less similar and hence the two species cannot be distinguished on the basis of external symptoms.

Disease cycle: These fungi perpetuate in the absence of their natural hosts on diseased plant debris as mycelium in the infected tissues or as spores. Spore formation also takes place on dead fallen leaves under moist conditions. The spores or mycelium that stick to the grain also remain alive for a number of months under conditions of storage. Seedling and crown infections occur from the mycelium and spores borne on the seed or from diseased plant debris lying on or in the soil. Disease development is more severe if the temperatures at sowing time are high. Leaf infections develop under warm moist conditions and they spread readily from secondary conidial infections. Under favourable conditions the leaf spot phase may be quite severe at times, resulting in yellowing and drying-up of the plant. Weaker plants are more susceptible.

H. sativum is also known to occur on barley but whether the strains affecting barley and wheat are the same has not yet been fully investigated. As perfect stages of these fungi have not been observed under field conditions in India, these are not likely to play any role in the disease cycle.

Control. Seed treatment with organomercurial compounds will control the seed-borne infection and, thus, reduce the number of primary infections. Delaying the sowings for a fortnight to avoid high soil temperatures will also enable the plants to escape infection. A two- to three-year rotation and destruction of diseased plant debris will also reduce the inoculum for subsequent infections.

OTHER DISEASES

Yellow ear rot or Tundu disease of wheat. Yellow ear rot of wheat has been found to be severe in the states of the Punjab, Rajasthan, Uttar Pradesh and Delhi. In Delhi State the damage can be estimated as 1 to 2 per cent, but in some fields losses as heavy as 50 per cent have been observed (Vasudeva and Hingorani, 1952). The disease was first recorded by Hutchinson in 1917 from the Punjab and was subsequently recorded from Egypt (Fahmy and Mikhail, 1925), W. Australia (Carne, 1926) and China (Cheo, 1946). The foreign workers reported that the disease could not be reproduced with a pure culture of the causal bacterium (*Corynebacterium tritici*) and that presence of the wheat nematode (*Anguina tritici*) was essential in this connection. Chaudhury (1935), on the other hand, claimed to have reproduced the disease with a pure culture of the bacterium. Work done at the Indian Agricultural Research Institute (Vasudeva and Hingorani, 1952) has, however, proved conclusively that the presence of the wheat nematode along with the bacterium is essential for the successful reproduction of the disease.

The disease is characterized by the presence of yellow slime or gum in the inflorescence and parts of the stem. Narrow white flecks are prominent on the upper leaf blade. The gum forms sticky layers between the glumes and the stem and sheath, interfering with the growth of plants, thus resulting in the distortion of the parts. In the early stages the slime can be seen trickling down the ear but later it forms a hard brittle mass over the spike. The diseased spikes become curled and distorted before heading (Plate 75).

Effect of environment: Hutchinson stated that the disease appears only in badly drained areas and that high soil temperature was not conducive for the development of the bacteria. Vasudeva and Hingorani (1952) also found that the disease was more severe in January or February when the temperature was lower than in March and April. They also reported that the disease was more prominent around wells and water channels where soil moisture was high.

Control measures. The nematode galls, which are mixed with healthy grains, carry the causal bacterium and cause fresh infection. Therefore, the removal of galls can successfully control the disease. The galls can be only partially removed by screening and fanning; therefore, only partial control of the disease is possible by this method. Sedimentation by salt brine (40 lb. salt to 25 gal. water) and flotation in water have been found to be quite effective.

Ear Cockle disease. Another disease which is associated with yellow ear rot of wheat is the Ear Cockle disease which is caused by the eelworm, *Anguina tritici*. The nematodes can infect the plants in the seedling stage and cause twisting and distortion of leaves, and also, at times, enlargement of the stem. On the leaves small rounded areas or galls make their appearance. The infected plants are shorter and thicker than the normal ones. If the infection is severe the seedlings die out. In the adult stage hard dark galls make their appearance in place of normal kernels. The glumes of such infected spikes spread apart.

The most common method of the dissemination of the disease is through the nematode galls being harvested along with healthy grains. On reaching the soil they become soft and liberate the larvae which infect the seedlings of the host. However, it has been shown that the larvae have a limited power of travelling and infecting the plants in the soil. Therefore, the spread of the disease by larvae is rather limited.

The disease can be effectively controlled by sowing clean wheat seed from which nematode galls have been removed as in the case of yellow ear rot of wheat.

Other diseases. Some of the other diseases of wheat also require mention. For instance disease caused by *Alternaria* has become important in some parts of India. The exact mode of perpetuation of the disease, the loss it is capable of causing and the conditions under which it can infect the host have yet to be determined. Similarly the *Molya* disease of wheat has become an important problem in certain areas of Rajasthan. Probably it is caused by a nematode. Detailed investigations are needed to draw definite conclusions regarding the mode of infection and the perpetuation of the disease.

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XI

PESTS

Wheat, fortunately, is relatively free from attack by insect pests in large areas where it is grown in the Indian Union. In Europe and America the crop has a number of very serious pests like the notorious hessian fly, *Phytophaga destructor* (Say), the chinch bug, *Blissus leucopterus* (Say), the wheat straw worm, *Harmolita grandis* (Riley), the wheat stem sawfly, *Cephus cinctus* Norton, to mention only a few, which regularly appear in the field as major pests causing serious losses. This has created, in those continents, difficult problems for both the farmers and the economic entomologists. India is indeed fortunate in regard to this problem. Although more than a dozen insect pests have been observed to infest wheat from the time it is sown till harvest, the following five insect pests and one nematode alone deserve mention:

1. Termites or white-ants, *Microtermes obesi* (Anardi) H. and *Odontotermes obesus* Ramb.
2. The grasshopper, *Chrotogonus* spp.
3. The wheat aphids, *Toxoptera graminum* R. and *Aphis maidis* Fitch.
4. The stem borer, *Sesamia inferens* Wlk.
5. The pale green bug, *Eurygaster maura* Linn.
6. The nematode, *Anguina tritici* (Steinbuch) Chitwood.

It may, however, be emphasized that so far none of these pests has created any serious problem in our country, excepting that under conditions favourable to them there is always a danger of any of these assuming the status of a major pest.

Of the two species of termites mentioned above, *M. obesi* (Fig. 13, *2*, *2a*) is more serious and more widely distributed. The other species, *O. obesus* (Fig. 13, *1*, *1a*) is more a mound-building species and appears in the field only at times in association with *M. obesi.* The damage to wheat is both in the nursery as well as to the grown-up plants. In Delhi and the Punjab where wheat is sown about the beginning of November, termites have been observed to damage one- to two-month-old seedlings. Sometimes there is an attack on the ripening crop also. In Pusa (Bihar), termites have been observed to attack wheat seedlings. In Hoshangabad (Madhya Pradesh), the damage is caused in the later stages of plant growth when ears make their appearance. Observations, time and again, have shown that the incidence of this pest is restricted to certain well-defined areas that are either dry or far away from big irrigation channels. Wheat grown in newly reclaimed areas and particularly wheat grown without any kind of irrigation, affords suitable breeding grounds for the pest.

The control of termites attacking agricultural crops in the field is one of the most difficult and baffling problems in applied entomology. That these have got preference for certain types of soil has been observed by more than one worker, and it has been shown that crops raised on sandy and loose soils are more susceptible to their attack than those grown in heavier and more compact soils. Jhaveri (1917) observed that the pest was absent in wheat cultivated in black soil areas of northern Gujarat, while Brown (1917) reported a greater attack in wheat grown in light soils as compared to that grown on heavy soils. At any rate, termites nest underground up to a depth of about ten feet or more and breed at a terrific rate, the queen laying as many as 30,000 eggs per day in some of the Indian species. The peculiar habit of the primary reproductive pair living deep underground combined with their tremendous rate of reproduction render the termite problem specially difficult. As Fletcher (1917) has observed, "to deal directly with these termites in wheat areas seems to be rather impossible". Therefore, the older and well-tried method of applying crude oil emulsion in the irrigation channels at the rate of three to four gallons per acre is still to be relied upon till the plants get themselves well established in the field. One or two timely irrigations also reduce the infestation to a great extent and even plants seriously damaged and appearing to be dying revive after the flooding of the infested fields. This may be due to the fact that the whole of the root system has not been completely damaged. Aldrin, Dieldrin and Chlordane have given encouraging results in other wheat-growing countries, but these organic insecticides are still in the experimental stage in this country.

Among the few grasshoppers that damage wheat plants, mention may be made of *Chrotogonus* spp. (Fig. 13, *5*). In certain years the pest has been reported to cause serious damage to young plants. The problem of the control of the grasshoppers is fortunately not very difficult. It is possible to obtain very satisfactory results either by dusting with benzene hexachloride or by using baits prepared according to the following formula:

Bran	80 lb.
Sodium fluosilicate	2 lb.
Molasses	2 lb.
Water	as required

The bait is scattered in the field and on bunds where egg laying has been detected and where the young hoppers emerge and congregate. The bait should be applied preferably early in the morning, and should be fresh. Dusting with 5 to 7 per cent BHC at the rate of 10–15 lb. per acre will be found beneficial against the more mature grasshoppers. The dusting should be done either by a hand duster or a power duster according to the degree of infestation.

The wheat aphid, *T. graminum* (Fig. 13, *4*), has got a world-wide distribution, destroying as it does from 1 to 3 per cent of the world's wheat production (Metcalf *et al.*, 1951). In India too this species is commonly met with on wheat, barley, oats and some other plants like *Cyperus rotundus* and *C. niveus*. Another species, *Aphis maidis* Fitch (Fig. 13, *3*) has also been observed in wheat in Delhi, Pusa (Bihar) and Karnal (Punjab). These aphids feed on the stem of the plants and unripe heads and drain off the sap. The aphids which are few in number at the beginning go on reproducing and multiplying at a very high rate so that at times, and under favourable ecological conditions, they literally cover and hide the ears and other areas of the plant near the ear region. It is not difficult to control this pest and satisfactory results can be obtained by dusting infested fields with 1 to 4 per cent actual nicotine at about 10-15 lb. per acre according to the degree of infestation. Dusting the infested crop with 3 to 5 per cent benzene hexachloride at about 8–10 lb. per acre will also give satisfactory results.

The stem borer, *Sesamia inferens* (Fig. 13, *6, 6a*), has sometimes been reported doing some damage to the crop in the Punjab, Surat, Nagpur, Pusa (Bihar) and Indore. The natural host plants of this pest are maize, rice and sugarcane and it is in the absence of these food plants that it migrates to wheat and other plants to carry over its brood. In Indore, in 1953, the pest was found seriously affecting some of the exotic varieties of wheat. The indigenous varieties were observed to be more resistant. The affected plants were sprayed with 0·25 per cent wettable DDT and this brought the pest under control. The burning of the stubbles that usually harbour a large number of the caterpillars and pupae of the pest will also ensure an adequate protection against the depredations of this pest.

Within recent years a pale green bug, *Eurygaster maura* Linn., has been observed to be spreading on the ears of wheat in the Kulu Valley and in Himachal Pradesh. The ears dry up as the bugs suck the juice from the developing grains in the ears. Dusting the crop with 5 per cent BHC has been found to control the pest effectively.

A nematode pest, *Anguina tritici* (Steinbuch) Chitwood (Fig. 13, *7*), sometimes causes serious damage to wheat. It causes malformation in wheat and other cereals by producing galls or cockles instead of normal wheat grains. Sometimes gall formation on leaves also occurs in young seedlings which may eventually be killed. The infestation spreads by the sowing of grain with which galls have become mixed, the latter containing the second-stage larvae. The galls hatch in the soil under the influence of certain chemicals produced by the roots of the host plant. The nature of these 'hatching factors' has not yet been fully understood. The larvae invade seedlings but lead an ectoparasitic life around the growing point. Occasionally some may bore into the tissues to give rise to the curling of the leaves. With the formation of ears the parasites enter the embryo, moult and attain the reproductive stage. A very large number of eggs are laid which hatch into first-stage larvae that immediately change into the resistant second stage.

Use of non-infested seeds is perhaps the most important method of control of the pest. Infected fields should not be sown with the susceptible crop for one or two seasons till the field is cleared of the pest.

Wheat in storage is infested by a large number of insect pests and it is here that the damage and loss are more severe than in the field. The more important of these pests in the Indian Union are:

1. The grain weevil, *Sitophilus oryzae* Linn. (Curculionidae: Coleoptera) (Fig. 14, *1*).
2. The lesser grain borer, *Rhizopertha dominica* Fab. (Bostrychidae: Coleoptera) (Fig. 14, *2*).
3. The *khapra*, *Trogoderma granarium* Everts (Dermestidae: Coleoptera) (Fig. 14, *3, 3a*).

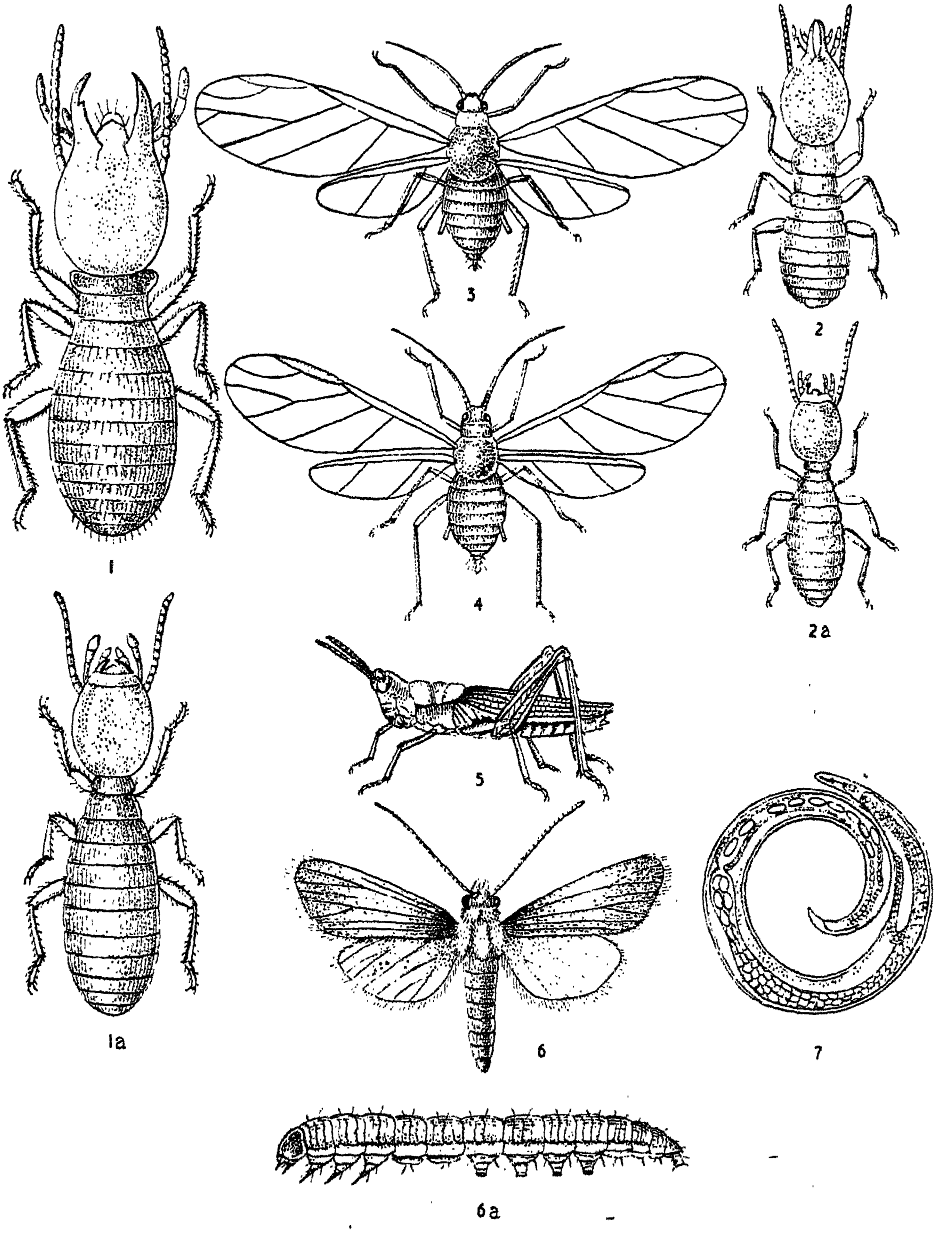

FIG. 13. Field pests of wheat
1, 1a, *Odontotermes obesus* Ramb.; 2, 2a, *Microtermes obesi* (Anardi) H.; 3, *Aphis maidis* Fitch.; 4, *Toxoptera graminum* R.; 5, *Chrotogonus* spp.; 6, 6a, *Sesamia inferens* Wlk.; 7, *Anguina tritici* (Steinbuch) Chitwood.

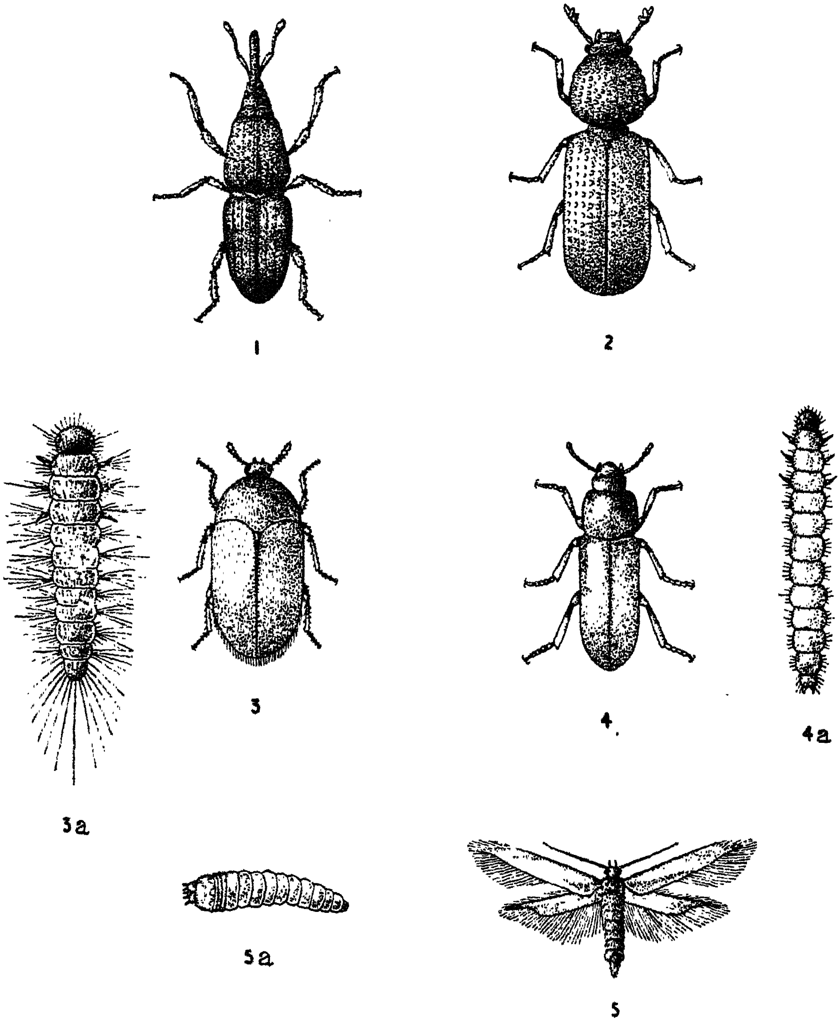

FIG. 14. Storage pests of wheat
1, *Sitophilus oryzae* L.; 2, *Rhizopertha dominica* Fab.; 3, 3a, *Trogoderma granarium* Everts; 4, 4a, *Tribolium castaneum* Herbst; 5, 5a, *Sitotroga cerealella* Olivier

4. The flour beetle, *Tribolium castaneum* Herbst (Tenebrionidae: Coleoptera) (Fig. 14, *4*, *4a*).
5. The Angoumois grain moth, *Sitotroga cerealella* Olivir (Gelechiidae: Lepidoptera) (Fig. 14, *5*, *5a*).

The first two pests in the above list, namely, *Sitophilus oryzae* Linn. and *Rhizopertha dominica* Fab., are capable of causing severe damage even to healthy grains. Both the adults and larvae feed on the grains, at times reducing them to mere shells. The damage by these two pests, however, increases in magnitude in the rainy season when wheat has absorbed a moisture content of 10 per cent or more. Unlike the first two, *Trogoderma* (*khapra*) is capable of causing damage only in the grub stage. The adult is completely harmless and does not feed on the grain. The pest, however, thrives well only in dry conditions and even at a very low moisture content in the grain. *Tribolium* belongs to the category of beetle pests of stored grain that are not primary pests but feed on broken grains, grain dust or grains damaged by other pests. It is, therefore, primarily a pest of prepared cereal products like *atta*, *maida*, *suji*, etc. *Sitotroga cerealella* is a moth distinguishable by its brown colour and narrow wings; the damage caused by this pest is again by its larvae and is at times very serious. Severe damage is, however, not likely to be occasioned until the grains gain a moisture content of 10 per cent or more.

The most important precaution to be taken when storing wheat is that the grain should be dry and free from initial infestation. As Thompson (1930) observes, "Since organisms increase in geometrical progression, the survival in each generation of even two or three females above the number necessary to maintain the population at an even level may produce, in a relatively short time, disastrous results". In the case of storage insects particularly we have to be careful from the very beginning, because early neglect makes multiplication of the pest easy.

It is always advisable, therefore, to store wheat in as dry a condition as possible. In a country like India where solar energy is both bounteous and plentiful, drying of wheat can be achieved during the summer months with almost no expenditure and the least amount of difficulty. There is, however, the danger of infestation from July to October or November and it is during this period particularly that care has to be exercised. If found infested, further treatments should be given to the grain. The nature of the treatment will depend on whether the grain is to be used for consumption by human beings or cattle or for seed purposes. For human or cattle consumption, the wheat can very easily be fumigated with a mixture of ethylene dichloride and carbon tetrachloride (3:1) used at the rate of 30 to 40 pounds for 1,000 maunds of wheat depending on the degree of infestation. The exposure period is 24–48 hours. This is the practice that has been widely adopted in this country for the last decade or so and found effective. Fumigation of grain meant for consumption can also be carried out with methyl bromide, hydrocyanic acid gas, ethylene dibromide, carbon disulphide, etc. But these fumigants can only be handled by trained personnel. Recently, Muthu and Pingale (1955) observed that ethylene dibromide when used at the rate of 10 cc. for a 200 lb. bag (impregnated with lindane) completely controls insect pests and that the fumigant also evaporates from the bags more or less completely. These authors, therefore, felt that it is not unsafe to introduce the fumigant directly into the bag by injection. According to Narayanan *et al.* (1956) and Bhambhani and Rout (1955), carbon tetrachloride, used alone, is found to be a better fumigant than a mixture of ethylene dichloride and carbon tetrachloride and also ethylene dibromide for killing the storage pest, *Tribolium castaneum*, in wheat.

Wheat meant for seed purposes can be better protected than the food grains, because whereas chemically treated food grains are never completely free from possible hazards to human beings and livestock, this serious limitation does not exist in the case of seed grains. Pradhan and Mookherjee (1958) observed that wheat seed uniformly mixed with 10 per cent DDT, 0·5 per cent *gamma* BHC, 0·5 per cent Dieldrin or 0·2 per cent Pyrethrin at the rate of 1 part of insecticide for 1,000 parts of grain by weight attains a high degree of protection against the majority of storage pests except *Trogoderma*. Protection against *Trogoderma* can also be ensured when the dose of the insecticide is increased to four parts in a thousand. Alternately, the wheat seed can be disinfested by fumigation with a mixture of ethylene dichloride and carbon tetrachloride as and when necessary, for protection against any kind of insect damage. Even a dosage of 100 pounds of the fumigant per 1,000 maunds of grain for a 24-hour exposure, ten repeated fumigations at fortnightly intervals with 40 pounds per 1,000 maunds for 24 hours and as long an exposure as seven days with the recommended dose of 40 pounds per 1,000 maunds, have been found to be safe from the point of view of the viability of the wheat seed.

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XII

SOILS IN RELATION TO WHEAT

Wheat is grown on a variety of soils in India and, in fact, we cannot exactly define wheat soils. Texturally, lighter types of soils are most suited for wheat culture, but porous and excessively drained soils have to be avoided for successful wheat growing, as the moisture requirement of the crop is usually high. Similarly, heavy soils with bad structure are not very suitable for wheat, although heavy soils with open structure are excellent wheat soils in the dry-farming areas. From soil considerations, therefore, the requirements of wheat demand a loamy texture, good structure and moderate water-holding capacity. Wherever such conditions are available wheat can be grown, although the yields obtained depend on many factors.

Wheat is mostly grown in northern, north-western and central India. Wheat-growing areas can very broadly be divided into five main soil divisions, viz., (1) the Gangetic alluvium of Uttar Pradesh and Bihar, (2) the Indus alluvium of the Punjab, (3) the black soil regions of central and southern India, comprising Madhya Pradesh and parts of Maharashtra and Mysore, (4) the hilly regions of the Himalayas and the Siwaliks, and (5) the desert soils in Rajasthan (only under irrigated conditions).

SOILS OF WHEAT-GROWING AREAS

1. Gangetic alluvium of Uttar Pradesh and Bihar. From the agricultural point of view these soils are very fertile. They are deficient in nitrogen and humus and also generally in phosphoric acid but not in potash and lime.

(*a*) *Uttar Pradesh* (*also Delhi State*)*:* In Uttar Pradesh there are broadly three soil divisions in which wheat is grown. These divisions are: (a) the Gangetic alluvium, (b) the black soils in the Bundelkhand area, and (c) the *karail* soils of the Vindhyan region. The soils of the Gangetic alluvium in Uttar Pradesh are described below. The soils in the other two divisions being mainly a sub-group of the black soil group are described under that heading.

The Gangetic alluvium in Uttar Pradesh has been subdivided by geologists into two groups, namely, the old alluvium and the new alluvium. The old alluvium is mature and of a texture varying from loam to sand, generally of dark brown colour; some varieties of this are underlaid by *kankar* while the new alluvium is generally sandy to silty in texture containing less *kankar*. The average annual rainfall varies from 35 inches to 45 inches. The maximum temperature varies from 95°F in May to 64°F in January and the minimum temperature varies from 90°F in May to 55°F in January. The mean maximum temperature in May exceeds 105°F.

In general formation, the alluvial soils in Uttar Pradesh have been described by Agarwal and Mehrotra (1952, 1953), and Agarwal *et al.* (1953, 1956, 1957) in four broad associations: (i) the riverine soil (referred to above as new alluvium), (ii) the soils on flats, (iii) the upland soils, and (iv) the lowland soils. The soils on flats and upland soils are ideally suited for wheat, but the soils in lowlands can also grow wheat provided they are not highly salt-infested and are otherwise structurally suited for wheat culture.

As already mentioned the predominant wheat soils are those on the flats and uplands. The soil types found in the flats in Aligarh district are light and ashy-brown to light brownish-red in colour with a sandy loam to loam texture. The subsoils are normally heavier in texture than the surface soils and there is a bed of *kankar* in the bottom of the profile. The structure is granular and the moisture relationships are good for wheat culture. The soils are normally deficient in N, low in P_2O_5 and adequately supplied with potash. Wheat responds to N and P_2O_5, and green-manuring on this type of soil is considered ideal for the maintenance of soil fertility. At least two irrigations are necessary for successful growth of wheat crop.

The soils on uplands are in fact ideally suited for wheat culture. They are comparatively dark brown in colour and light in texture than their counterparts in flats. The drainage is good, but the subsoils being comparatively heavier, the moisture-holding capacity in the profile is good and the lighter surface soil encourages healthier root development and proper aeration. The water-table is usually lower than 20 inches and *kankar* formation is, as such, absent except in much lower depths in profiles. The soil pH value is about 6·2–6·5. There is no salinity hazard and the soils are ideally suited for irrigation. Nutritionally, both N and P_2O_5 are much in deficit and the combination of the two fertilizers is known to produce excellent wheat yields. Green-manuring is an ideal practice in these soils, especially under canal-irrigated conditions. Nearly 95 per cent of wheat grown on such types of soils is irrigated, the sources of water being canals, tubewells or ordinary gravity wells. Three irrigations are usually needed for growing a successful wheat crop.

Analytical data in respect of two soil profiles for the above two soil associations are reported by Agarwal and Mehrotra (1952).

Adaptation of soils belonging to other types for wheat culture is also possible by providing suitable environmental factors, and no general rule in regard to soil characters suitable to wheat in the large alluvial tract can therefore be laid down. An example of such adaptation is furnished by the analysis of soils in the districts of Agra and Etah in U.P., where soils with a pH value of 8·3 are known to carry moderately good wheat crops.

The analytical data of such soil profiles growing wheat in the district of Etah and in Agra district of Uttar Pradesh are given in Tables XXI and XXII.

From the analytical data given in Tables XXI and XXII, it is quite clear that the organic matter and nitrogen are very low in the Etah soil; in the Agra soil profile they are still lower. Available P_2O_5 is low in the surface soils. Total K_2O is quite high but its availability is very much limited.

Delhi State can be divided into four natural soil divisions. They are: (1) Jumna *khadar*, the new alluvium, (2) *bhangar*, the old alluvium, (3) *dabar*, the low-lying area, and (4) *kohi*, the rocky area. Good wheat crops are grown in *khadar*, *bhangar* and *dabar* areas.

TABLE XXI. ANALYTICAL DATA FOR A SOIL PROFILE NEAR ETAH (Oven-dry basis; Deshmukh, 1958)

Depth in inches	pH	% Organic carbon	% Total N	% Total P_2O_5	% Total K_2O	% Available P_2O_5	% Available K_2O	Texture
0–6	8·3	0·242	0·048	0·077	0·695	0·0014	0·0039	Loam
6–17	8·2	0·182	0·038	0·080	0·924	0·0030	0·0052	Loam
17–24	8·0	0·183	0·034	0·053	0·922	0·0025	0·0051	Clay loam
24–46	8·0	0·153	0·037	0·063	1·111	0·0025	0·0061	Silty loam
46–62	8·0	0·107	0·024	0·063	1·030	0·00081	0·0065	Silty loam

TABLE XXII. ANALYTICAL DATA FOR A SOIL PROFILE NEAR AGRA (Oven-dry basis; Ravi Kumar, 1957)

Depth in inches	pH	% Organic carbon	% Total N	% Total P_2O_5	% Total K_2O	% Available P_2O_5	% Available K_2O	Texture
0–5	7·8	0·187	0·022	0·099	0·386	0·00056	0·0063	Loamy sand
5–19	7·6	0·109	0·020	0·113	0·530	0·00096	0·0036	Sandy loam
19–41	7·5	0·047	0·010	0·103	0·320	0·0012	0·0030	Loamy sand
41–72	7·8	0·036	0·010	0·062	0·422	0·0017	0·0035	,,

Raychaudhuri and Sankaran (1952) reported that *khadar* soils are quite rich in organic matter, organic carbon, total P_2O_5 and total K_2O. Due to high nutrient status, good wheat yields are obtained in these soils.

(*b*) *Bihar:* All the districts of Bihar grow wheat but Shahbad, Monghyr and to a lesser extent Gaya, Saran, Champaran and Muzzafarpur are the main wheat-growing areas.

The alluvial soils of Bihar can broadly be distinguished into two divisions, viz., (i) alluvium north of the Ganges, and (ii) alluvium south of the Ganges.

(I) ALLUVIUM NORTH OF THE GANGES: These soils are distributed over a large area comprising Tirhut, Patna and Bhagalpur divisions. The soils vary from clay loam to sandy loam and are neutral to alkaline in reaction. Where the calcium carbonate content is high, the pH is above 8·00 and the lime content varies from 0·5 to 20·25 per cent. The soils are rich in total as well as available potash, but appear to be deficient in phosphoric acid. The average annual rainfall varies from 35 inches to 50 inches. The maximum temperature varies from 85°F in January to 100°F in May and the minimum temperature varies from 50°F in January to 90°F in May. The analytical data of a typical soil profile from Pusa, north Bihar, is reported by Dhamija (1955). The soils of Pusa are highly calcareous but lime concretions do not appear in any part of the profile. Surface soil contains enough nitrogen which falls rapidly below six inches; available P_2O_5 is low. The soils seem to contain moderate amounts of available manganese.

(II) ALLUVIUM SOUTH OF THE GANGES: The soils of this division are comparatively heavier in texture than those north of the Ganges. Both available potash and phosphoric acid are also higher. Calcium carbonate content is lower. The soil reaction is almost neutral but becomes acidic in the southernmost parts.

A report of the detailed soil survey of south Monghyr and east Gaya up to the Phalgu river is available (*Final Rep., All India Soil Surv. Sch.*, 1953). The eastern portion covering the south of the Kharagpur Hills is sandy, having a somewhat rocky subsoil. Winter crops do not grow well in this area. There is extreme deficiency of phosphoric acid, particularly in the subsoil. Nitrogen and potash are fairly high. The area between Kiul and Sakri rivers contains stiff clayey soils with sandy subsoil and is more fertile, but the nitrogen content is low. There is just sufficient phosphoric acid in the surface and subsoils. Beyond Sakri the soils are again of a light texture. In the area between Wazirganj and the Phalgu river, both the surface and subsoils are stiff clays. The soil is rich in total but not in available phosphoric acid, contains a high percentage of potassium, and the nitrogen content is fairly good. The lands growing winter crops contain a higher percentage of available phosphoric acid compared to paddy soils.

2. Indus alluvium in the Punjab. Majority of soils are loams or sandy loams having a soil crust of varying depth. The soils have generally an alkaline reaction; they are adequately supplied with phosphorus and potassium, but are lacking in organic matter and nitrogen. The soils have no definite profile characteristics. Calcium carbonate concretions are usually met with in the lower layers. Both under irrigated and unirrigated conditions wheat is the principal crop in the winter season. The average annual rainfall varies from 20 to 40 inches. The maximum temperature varies from 68°F in January to 100°F in May and the minimum temperature varies from 40°F in January to 90°F in May.

Total manganese, copper, zinc and cobalt were determined in six profiles from different soil climatic zones of the Punjab (*Rep. agric. Chem., Punjab*, 1954–55). In the surface six-inch layer, manganese varied from 546 to 690 ppm., copper from 14 to 39 ppm., zinc from 50 to 79 ppm. and cobalt from 12 to 20 ppm. All the soils appear to be rich in the total amounts of micronutrients. Exchangeable manganese decreases with increase in pH value, the quantity varying from 45 to as low as 2·5 ppm. (in Ludhiana).

The analytical data of a typical soil profile in the Indus alluvium in the Punjab at Karnal is reported by Dhamija (1955).

3. Black soil regions of central and southern India. The typical soils derived from the Deccan trap is the *regur* or the black cotton soil. It is common in Bombay, Madhya Pradesh and parts of Mysore. It is comparable with the chernozems of Russia and with the prairie soil of the cotton-growing areas of the U.S.A. and especially with the black adobe of California. It is derived from two types of rocks, viz., (1) the Deccan trap, and (ii) ferruginous gneisses and schists. The former type sometimes attains considerable depth while the latter is generally of medium to shallow depth. The average annual rainfall varies from 20 to 40 inches. The maximum temperature varies from 75°F in January to 90°F in May and the minimum temperature varies from 70°F in January to 80°F in May.

Many black soil areas have a high degree of fertility but some, especially in the uplands, are rather poor. They are somewhat sandy on the slopes. These soils are moderately productive with a good monsoon. In the valleys they are darker, deeper and richer and are constantly enriched by additions washed down from the hills.

Black soils are highly argillaceous, very fine grained and dark coloured. They contain a high proportion of calcium and magnesium carbonates. They have high moisture-holding capacity and are exceedingly sticky when wet. Owing to considerable contraction on drying, large and deep cracks are formed. They contain much iron and fairly high quantities of lime, magnesia and alumina. Potash contents of these soils show a wide range. They are poor in phosphorus, nitrogen and organic matter. In all black soil areas in general and in those derived from ferromagnesian schists in particular, there is generally a layer rich in *kankar* nodules formed by segregation of calcium carbonate at some depth below the surface and above the weathered rock.

Agarwal *et al.* (1956) studied the morphological and chemical characteristics of a group of black clay soils on which wheat is grown, popularly known as *karail*, occurring in the lower Gangetic basin in Uttar Pradesh. These soils are distinct from their zonal associates developed under similar environments on the Gangetic alluvium and show greater resemblance with the *mar* of Bundelkhand or *regur* of central India. They possess a parent material similar to the black cotton soils. Their formation has been attributed to a transported basaltic type of alluvium received from the Ganges.

In Bombay, soils derived from the Deccan trap occupy quite a large area. On the uplands and on the slopes soils are light coloured, thin and poor. On the lowlands and in the valleys, deep and relatively clayey black soils are found and these are quite fertile. On the low-lying soils winter crops including wheat are cultivated. In the valleys of the Tapti, the Narmada, the Godavari and the Krishna rivers, heavy black soil is often 20 feet deep. Some of the best irrigated wheat crops of the State are grown in the deep black alluvial soils of the Tapti Valley in Khandesh and along the Godavari in Ahmednagar.

Medium black soils which are comparatively lighter in texture and have a layer of decomposed trap rock, called *murrum*, two or three feet below the surface which prevents water-logging to a great extent, are very suitable for irrigated wheat. Shallow black soils are found in the districts of Wardha and Nagpur.

The black soils are very heavy and contain up to 65 to 80 per cent of finer fractions. They have generally a high base status and high base exchange capacity.

The profiles of virgin and medium black soils at Nagpur and Akola have been examined by Bal (1943). Morphological examinations show that the soils gradually change in colour (from deep black to light) in the depths of the profile. The calcium carbonate content increases with depth. Clay content varies from 35 to 50 per cent and organic matter content is low. The analytical data of such a typical profile from Nagpur is reported by Padoley (1955).

Padoley and Tamhane (unpublished) studied black soils of Madhya Pradesh developed on different parent materials for physical, chemical and mineralogical composition. Although these soils do not show any difference in outward appearance, the differences of parent rocks are reflected in the physical and chemical composition of the soils.

Soils of the Narmada Valley are deep and clayey in texture with high water-holding and high water-releasing capacity and do not indicate necessity of frequent irrigation (Tamhane and Deshpande, 1955).

In Mysore there are considerable stretches of black soil comprising the districts of Belgaum, Bijapur, Dharwar and Gulbarga where good crops of wheat are raised, specially if the late rains are favourable. Lime content in these soils varies from 4·5 to 6·2 per cent, nitrogen from 0·04 to 0·06 per cent, phosphoric acid from 0·02 to 0·03 per cent and potash from 0·13 to 0·19 per cent.

4. Hilly regions of the Himalayas and the Siwaliks. The formation of these soils is mainly governed by the characteristic deposition of the organic matter derived from the forest growth on the hills. Broadly, two conditions of soil formation may be distinguished, viz., (i) soils formed under acid conditions with presence of acid humus and under low base status, and (ii) soils formed under slightly acid or neutral condition with high base status which is favourable for the formation of brown earths. The hilly soils growing wheat are found in Uttar Pradesh, Punjab and Himachal Pradesh. The average annual rainfall varies from 40″ to 80″. The maximum temperature varies from 70°F in January to 90°F in May and the minimum temperature varies from 60°F in January to 80°F in May.

In Uttar Pradesh, the sub-Himalayan tract comprises three distinct portions, viz., *bhabar* area immediately below the hills, *tarai* and plains. Four major groups, i.e., red loams, brown forest soils, podsols and transitional podsols, have been observed in the Himalayan tract, of which brown forest soils and podsols are predominant (Mukerji and Das, 1940, 1941, 1942). In *tarai* area, soils have been classified into three major textural groups by Agarwal and Mehrotra (1953) : clay loam, loam and sandy loam. Loam has been further subdivided into three classes depending on its lime status.

In the Punjab, Taylor *et al.* (1935) conducted investigations on the forest soils of the Kulu Division. The soils are related to the podsols but have significant differences, mainly due to the relatively high calcium content of the top layer. A number of surface soil samples collected from Kangra district show that soils are sandy loam to clay loam, pH varies from 4·9 to 6·9, organic matter is from 0·8 to 4·0 per cent, while available phosphorus is low. The analytical data of a soil profile at the Wheat Breeding Sub-Station, I.A.R.I., Simla, reported by Lote (1954), showed that the soils are quite rich in nitrogen and potash while available phosphoric acid is medium to high.

5. Desert soil (Wheat grown only under irrigated conditions). A large part of the arid region included in Rajasthan and south Punjab lying between the Indus and the Aravallis, is affected by desert conditions of geologically recent origin. These soils consist mostly of sand and are poor in organic matter with varying amounts of calcium carbonate. The average annual rainfall varies from 10 inches or less to 20 inches. The maximum temperature varies from 70°F in January to 95°F in May and the minimum temperature varies from 60°F in January to 85°F in May.

Some of these soils contain high percentage of soluble salts and possess high pH, the limiting factor being water. Good wheat crop is obtained under irrigated conditions.

THE CONCEPT OF A SEED VILLAGE, A MIRACLE SEED

A miracle seed—the idea of a Seed Village—was sown in Jounti in November, 1964. The Pusa Scientists and students led by Dr. M. S. Swaminathan, who visited the village, told us that with the development of high yielding varieties of crop plants altogether new vistas have been opened up in the yield and income possibilities of small holdings. They told us that if the new varieties of wheat and bajra are cultivated properly even a farmer with 3 acres can get a net income exceeding Rs. 3000 per year. Since good seed is a basic input and is essential for taking full advantage of fertilizer and water, they urged us to take to seed production as a skilled trade. If the entire village became a seed producing unit, they said that in two seasons, there will be enough seeds of high quality to cover the entire Delhi State. They also said that they cannot offer any help except their knowledge and their own physical labour on holidays. Impressed by their sincerity we agreed to sow the seed which has grown to the present Seed Village.

Salient features of Jonti
Seed Village

Total population	...	2050
No. of families	...	300
Total area	...	1472 acres
Area (irrigated)	...	1152 acres
Area with assured irrigation	...	500 acres

Source of irrigation

(i)	No. of wells	...	103
(ii)	Wells with persian wheels	...	76
(iii)	Wells with diesel pumps	...	1
(iv)	Tube well (Shallow cavity)	...	16

Area under improved varieties

Wheat (1966-67 rabi)	400 acres
Hybrid bajra (Kharif '67)	300 acres

On November 14, 1964, the staff and students of the Botany Division of the Indian Agricultural Research Institute visited the village, laid out a demonstration plot with high yielding dwarf varieties and urged the farmers of Jonti to form a "Forty Maund Wheat Club" and convert this village into a seed village. At that time most of our farmers were getting less than 20 maunds per acre of wheat even in irrigated lands. We therefore remained sceptical about the possibility of raising 40 maunds or more per acre, but to our pleasant surprise, several of us harvested during April 1965, 40--50 maunds per acre with dwarf wheat varieties grown in the way the Pusa Scientists recommended.

HYBRID BAJRA—STORY OF HOPE

During the kharif season of 1965, some of us raised 40-45 maunds of Bajra by growing hybrid strains in the same field where we had raised wheat during the *rabi* season. This was an eye opener to us and all of us considered getting 100 maunds of grain per acre per year as a miracle. We therefore willingly agreed to the suggestion of the Pusa scientists that the village should concentrate on the production of high quality seeds of new varieties and thereby develope seed production as a skilled trade. In November, 1965, we organised a Seed Cooperative named the Jawahar Jonti Seed Co-operative Limited and this society was inaugurated by the then Chief Commissioner of Delhi.

WHEAT—STORY OF PLENTY

During 1966 wheat season we produced pure seed of dwarf wheat varieties Lerma Rojo and Sonora 64 and obtained as high as 62 maunds per acre in many fields. We distributed the seeds all over the country. Even within a short time, the fame of this society spread all over the country and we have received indents for seeds from all the wheat growing regions of the country. We are trying our best to increase greatly our seed production target, so that we can meet not only the needs of the Delhi State but also those of some of the adjoining areas.

Since 1965, many changes have taken place in our village. Agriculture is no longer the dull and monotonous profession it used to be. We now eagerly await every sowing and harvesting season. Double cropping which was the exception before, has now become the rule. Tubewells have sprung up where none existed before, flourescent lamps radios and fans adorn many of our homes and a new life has come into the village. We feel so happy when Pusa Scientists like Chaudhary Amir Singh, Shri Nandkeolyar, Dr. Bakshi and Dr. Swaminathan visit us and in turn, we take every opportunity to visit the fields of Pusa Institute and see the marvels taking place there.

The members of the Society decided in 1966 to put up a Seed Processing Building so that we can grade the seeds, treat them with chemicals, and process and market them scientifically. We believe that this is the first venture of its kind put up by farmers with small holdings and poor means. We are proud that our Society has the honour of bearing the name of late Pandit Jawahar Lal Nehru, founder of Modern India. We fondly recall his last statement in which he wanted his mortal remains to be mingled with the soil of India's villages. We are confident that with the blessings of Shrimati Indira Gandhi, our beloved Prime Minister, the Society will grow further and the seed in the form of the seed village concept sown in Jonti by the Pusa Scientists will grow into a fine tree and will stimulate the birth of many such Seed Villages all over the country.

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विचित्र बीज का निर्माण

बीज गांव की विचार-धारा—विचित्र बीज

बीज गांव की विचारधारा की नींव नवम्बर १९६४ में पड़ी, जब पूसा के विज्ञानिक और विद्यार्थी डा० एम० एस० स्वामीनाथन के नेतृत्व में हमारे गांव पधारे और हमें बताया कि अच्छी उपज देने वाली किस्मों की खोज ने हमारी उपज और आय में एक नया अध्याय जोड़ दिया है । उन्होंने बताया कि अगर गेहूं और बाजरा की नई किस्मों को नए ढंग से उगाया जाय तो एक साधारण किसान जिसके पास केवल ३ एकड़ भूमि है, साल भर में ३,००० रु० से भी अधिक कमा सकता है। क्योंकि खाद और पानी से पूरा पूरा लाभ उठाने के लिए साथ में उत्तम बीज का होना अति आवश्यक है, उन्होंने इस बात पर जोर दिया कि हम बीज उत्पत्ति को कुशल व्यापार का रूप दें । यदि पूरे का पूरा गांव बीज उत्पन्न करने में संलग्न हो जाए, तो उन्होंने कहा कि दो साल (बुआइयों) में ही यह गांव पूरी दिल्ली के लिए बीज की आवश्यकता पूरी करने लायक बन सकता है । उन्होंने यह भी नताया कि वह हमें अपने ज्ञान तथा छुट्टी के दिनों में शारीरिक परीश्रम के अतिरिक्त और किसी प्रकार की सहायता नहीं दे सकेगें । उनकी निस्वार्थ और विश्वासपूर्ण बात चीत से प्रभावित हो कर ही हमने नये बीज बोए जिन्होने हमारे गांव को "बीजगांव" का रूप दिया ।

बीज गांव की रूप रेखा

१.	कुल जनसंख्या	—	२०५०	
२.	कुल परिवारों की संख्या	—	३००	
३.	कुल क्षेत्र	—	१४७२	एकड़
४.	कुल क्षेत्र जिसमें सिंचाई का पूरा प्रबन्ध है	—	५००	एकड़
५.	सिंचाई लायक क्षेत्र	—	११५२	एकड़

सिंचाई के साधन

१.	कूपों की संख्या	—	१०३
२.	पारसी पहियों वाले कूंए	—	७६
३.	डीज़ल पंप वाले कूंए	—	१
४.	ट्यूब वेल	—	१६

अच्छी किस्में बोए जाने वाला क्षेत्र

१.	गेहूं (१९६६-६७)	—	४०० एकड़
२.	संकर बाजरा (१९६७-खरीफ)	—	३०० एकड़

१४ नवम्बर, १९६४ को बनस्पति विभाग, 'भारतीय कृषि अनुसंधान शाला' के विद्यार्थी और वैज्ञानिक हमारे गांव में पधारे और उन्होंने अधिक पैदावार देने वाली बौनी किस्मों की प्रदर्शनी भी लगाई और हमें इस बात की सलाह दी कि हम एक "चालीस मन क्लब" की स्थापना करें और इस गांव को "बीज गांव" में परिवर्तन कर दें। उस समय हमारे अधिकतर किसान २० मन प्रति एकड़ से भी कम गेहूं अच्छी सिंचाई के क्षेत्र में पा रहे थे। इसी कारण उपज को ४० मन तक ले जाने की संभावना बहुत कम दिखाई देती थी, परन्तु हमारे आश्चर्य की सीमा न रही जब हमारे कई भाइयों ने ४०–५० मन प्रति एकड़ से भी अधिक गेहूं की बौनी किस्मों की कटाई पूसा के वैज्ञानिकों के बताए हुए तरीके से बोने पर की।

संकर बाजरा—आशा की किरण

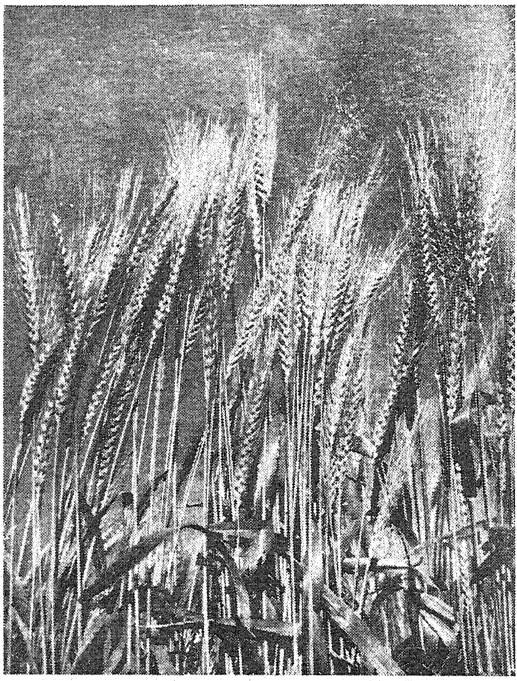
१९६५ खरीफ मौसम में हम में से कुछ किसानों ने उसी क्षेत्र में जहां गूहूँ की रबी की फसल बोई गई थी, संकर बाजरा उगा कर ४०–५० मन प्रति एकड़ कटाई प्राप्त की। इस सफलता ने ही हमारा मार्ग दर्शन किया और हम सब ने १०० मन प्रति एकड़ पैदावार प्रति वर्ष प्राप्त करने का विचार किया। अत: हमने पूसा के वैज्ञानिकों के इस सुझाव को प्रसन्नता से मान लिया कि पूरा गांव नई किस्मों के अच्छे बीज उत्पन्न करेगा और इस प्रकार से बीज उत्पादन को हम कुशल व्यापार का रूप देगें। नवम्बर १९६५ को हमने एक "बीज सहकारी सिमिति" बनाई और इस प्रकार जवाहर जौंती बीज सहकारी सिमिति का नामकरण संस्कार किया जिसका उद्‌घाटन देहली के तत्कालिन चीफ कमीश्नर ने किया।

गेहूँ—अधिक उपज की आशा

१९६६ की गेहूं के मौसम में हमने गेहूं की बौनी किस्में 'लरमा रारो' और 'सनोरा ६४' को बो कर ६२ मन प्रति एकड़ शुद्ध बीज का उत्पादन किया और यह बीज हमने देश के विभिन्न प्रान्तों में भेजा। थोड़े ही समय में यह समिति पूरे देश में इतनी विख्यात हुई कि हमें देश के हर गेहूं बोने वाले प्रांत से अगले वर्ष के लिए बीज लेने के लिए मांग आने लगी। अब हम जी जान से यह प्रयत्न कर रहे हैं कि उपज के लक्ष्य को अधिक से अधिक ऊंचा उठाया जाय, क्योंकि न केवल देहली अपितु उसके आस पास के क्षेत्रों की भी बीज की आवश्यकता को पूरा किया जा सके।

१९६५ के पश्चात् हमारा गांव पहले से बहुत बदल चुका है। कृषि अब पहले की तरह नीरस और निराशाजनक व्यवसाय नहीं रहा। अब हम हर बुआई और कटाई की बड़ी उत्सुकता से प्रतीक्षा करते हैं। दो बुआइंया प्रति वर्ष का रिवाज़ जो पहले असंभव था अब नियमित रूप से प्रत्येक किसान ने अपना लिया है। कई स्थानों पर बिजली के कूएं भी लग गए हैं। दम दमाती बिजलियां, रेडियो का मधुर संगीत और पंखों की शीतल पवन अब हमारे गांव में नए जीवन का संचार करती है और तब हमें बहुत ही प्रसन्नता होती है जब पूसा से श्री अमीर सिंह, श्री नँदकोलियार, डा० बख्शी और डा० स्वामीनाथन जैसे कर्मठ वैज्ञानिक समय समय पर गांव में पहुंच कर हमें अपने सुझाव देते रहते हैं। समय समय पर हम पूसा के खेतों को देखने जाते हैं और वहां पर जो खोज हो रही है उससे पूरा पूरा लाभ उठाने का प्रयत्न करते हैं।

समिति के सदस्यों ने १९६६ में निश्चय किया कि एक "बीज शोधनालय" बनाया जाए जहां पर बीजों का शोधन किया जा सके एंव वैज्ञानिक रीति से उनका समूचे देश में वितरण किया जा सके। हमारा विश्वास है कि यह अपनी प्रकार का प्रथम प्रयास है जो कि किसानों ने अपने सर्व साधारण उपलब्ध से आरम्भ किया है। हमें गर्व है कि हमारी सिमिति ने स्वर्गीय महान् नेता श्री जवाहर लाल नेहरू जी का नाम अपनाया है। हम बड़ी श्रद्धा से उनका अंतिम संदेश याद करते हैं जिसमें कि उन्होंने अपने नाशवान शरीर की भस्म भारत के किसानों के खेतों में मिलाने की इच्छा प्रकट की थी, जिसके पीछे एक महान् विचार था कि भारत का किसान सुखी एवं समृद्धिशाली हो। हमें पूरा विश्वास है कि हमारी प्रधान मन्त्री श्रीमति इंदिरा गांधी के आशीर्वाद से हमारी समिति अपना निश्चित लक्ष्य प्राप्त करेगी और जो विचार धारा पूसा के वैज्ञानिकों ने जौंती गाँव में प्रारम्भ की है वह देश के अधिकाधिक गाँवों को भी बीज गावों में परिवर्तित करने की प्रेरणा देगी।



Wheat Variety S-227

Hybrid Bajra No. 1

Gutenberg Printing Works, New Delhi-l

A few profiles have been examined in the cultivated areas of Jaipur and Ganga Canal colony of the Bikaner Division. The soils of Jaipur are of a yellowish-brown colour, have a hard and gritty consistency and lumpy structure, and contain *kankar* nodules within the profile. The soils of the Bikaner Division are yellowish grey and gritty but the lumps are friable and *kankar* nodules are few in number. The soils are sandy to sandy loam and loam, and are poor in nitrogen. From the data reported by Gupta (1958) it appears that these soils are medium in nutrient status in respect of both nitrogen and total P_2O_5; the soils are light in texture and water supply would act as a limiting factor for wheat production in these soils.

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XIII

AGRONOMY—MANURES AND FERTILIZERS

Though wheat is one of the most important crops of the country, the average yield of wheat in India is one of the lowest in the world. Soil fertility in India has become stabilized at a very low level because the plant nutrients removed from the soil by the various crops are not being replenished. The soils are only recuperated, to a limited extent, by natural processes working in the soil and in some cases due to occasional application of fertilizers and manures to the soil. Nitrogen and organic matter deficiencies are extremely widespread in Indian soils, phosphate deficiency is comparatively less, while potash deficiency is more limited. The wheat crop removes, on an average, 50 lb. nitrogen, 21 lb. P_2O_5 and 60 lb. K_2O per acre (Raychaudhuri and Chandnani, 1958). If, therefore, the yield of wheat is to be increased, and in particular, if full benefit is to be derived from improved varieties and the facilities for irrigation provided by the important river valley projects, sufficient plant nutrients will have to be added to the soil to make up the deficiencies.

Numerous field experiments have been conducted in India to ascertain the response of the wheat crop to various fertilizers, manures and their combinations under different soil and climatic conditions, by the Indian Council of Agricultural Research, the Indian Agricultural Research Institute and the Agricultural Departments of the states. The results of fertilizer trials, carried out at different experimental stations up to 1931 have been summarized by Vaidyanathan (1933). The results of later experiments have been summarized by Panse *et al.* (1947). The consolidated report of Fertilizer Experiments on Wheat under an Indo-U.S. Project, carried out during 1953–56, has been published by the Indian Council of Agricultural Research in 1959.

RESPONSE TO FERTILIZERS

Response of wheat to the application of nitrogen alone has been almost universal, whereas that to the application of phosphorus has been lower and more restricted. Positive response to the application of potash, either alone or in combination with other nutrients, has not been generally observed.

Nitrogen. From the results discussed by the Expert Committee on Manures and Fertilizers (Anon., 1953), it appears that on the Gangetic alluvium of Bihar the general response to ammonium sulphate (at Pusa) in unirrigated trials is very low. In the case of irrigated wheat also the response is not much, while in irrigated areas of the Gangetic alluvium of U.P. the response to ammonium sulphate has been quite appreciable at places like Gorakhpur and Kanpur. Rape cake (at 20 lb. N) gave about 100 per cent increased yield in the Pusa Permanent Manurial Trials, F.Y.M. gave about 250 per cent increase over the control and green-manuring with sunnhemp led to a 106 per cent increase in yield. The treatment with NPK gave 147 per cent increase over the control, compared to 138 per cent given by the NP treatment. A combination of green manure (sunnhemp) with superphosphate (80 lb. P_2O_5) gave a striking increase in yield of about 400 per cent over the control in Pusa.

On the soils of the Indus alluvium in the Punjab, at Patiala, ammonium sulphate at the rate of 23 lb. N gave a response of 26·4 per cent; at Jullundur, with 100 lb. N the response was 25·5 per cent with ammonium sulphate and 16 per cent with ammonium nitrate. With superphosphate alone, at the rate of 125 lb. P_2O_5, the response was 7·2 per cent at Jullundur and at Gurdaspur the response was 8·5 to 9·5 per cent increase with a dose of 56 lb. P_2O_5. Green-manuring (sunnhemp) gave an increase of 13·7 per cent at Hansi. In the black soils of Madhya Pradesh, with irrigated wheat, ammonium sulphate at a dose of 20 to 22 lb. N per acre has given responses of 21–23 per cent higher yield. At Jabbalpur, under unirrigated conditions, the response to ammonium sulphate, at a dose of 15 lb. N, was to the extent of 69 per cent on *kabar* soil. Application of F.Y.M. at Chindwara, under unirrigated conditions, at the rate of ten cartloads every year, was found to be better than 30 cartloads once in three years, giving an increase of 30·6 per cent over control. The combination of N and P has given much better response than either of them alone. Experiments conducted at B. R. College, Agra (Anant Rao *et al.*, 1954, 1957) indicated that by phosphate manuring of berseem and sunnhemp, the performance of the succeeding wheat crop was appreciably improved. In the case of berseem the residual effect of P_2O_5 was best with 66 lb. P_2O_5 per acre and sunnhemp green manure gave a better response at 160 lb. P_2O_5 than at 80 lb. P_2O_5 per acre.

Results of the Bihar Manurial Trials in cultivators' fields (1949–56) showed that the average response of wheat to 30lb. nitrogen, for the whole State and for the whole period of experimentation, was about 3·5 maunds per acre. Soils formed on gneiss seem to be on the same footing as alluvial soils in regard to response of wheat to manuring. The average response to 40 lb. P_2O_5 for the whole State was about 3·2 maunds per acre. Alluvial soils and soils formed on gneiss do not seem to differ in response. The average response to 40 lb. K_2O in alluvial soils and soils formed on gneiss are nearly of the same order, but alluvial clay soils seemed to have responded better than alluvial loam and sand.

Under the Indo-U.S. Project on Soil Fertility and Fertilizer Use, a number of agronomic trials were conducted on wheat at ten different centres for three years from 1953 to 1956. These experiments were spread over different soil and climatic conditions. The soils involved were the alluvial soils of the Indo-Gangetic Plain, red and yellow soils, medium black to deep black soils, hill soils and desert soils.

In simple trials, moderate to good response to the application of ammonium sulphate was obtained at all the centres, the response to 20 lb. nitrogen under irrigated conditions being two and a half maunds of wheat per acre. With an increase in the level of nitrogen to 40 lb. per acre increased response was obtained at all the centres. The responses to nitrogen were generally high in the Indo-Gangetic Plain.

The average response of unirrigated wheat was lower than that of irrigated wheat. Nitrogen at 20 lb. gave an additional yield of 1·7 md. per acre and by increasing the dose to 40 lb. nitrogen, an additional increase of 1 md. of wheat per acre was obtained.

As in the case of simple trials, in complex trials also a significant and appreciable response to application of ammonium sulphate was obtained at all centres under irrigated conditions. The average response with 20 lb. was 2·9 md./acre and at 40 lb. level it increased to 4·4 md. per acre. The response was highest in the medium black soil of Obedullaganj in Madhya Pradesh, followed by Banaras located in the Gangetic basin. But under unirrigated conditions, the response at Obedullaganj was only 0·3 md. per acre. The results are given in Tables XXIII and XXIV.

TABLE XXIII. AVERAGE RESPONSE TO AMMONIUM SULPHATE IN SIMPLE TRIALS ON CULTIVATORS' FIELDS (IN MD. PER ACRE) FROM 1953 TO 1956

Centre	Soil type	No. of trials	Yield without nitrogen	Response to doses of nitrogen/acre	
				20 lb.	40 lb.
		Irrigated			
Nawanshahr (Punjab)	Indus alluvium	201	17·4	3·8	6·5
Nilokheri (Punjab)	—do—	84	16·6	3·3	5·0
Bhadson (Punjab)	—do—	129	16·0	3·4	5·4
Alipur (Delhi)	Gangetic alluvium	121	16·6	2·8	5·8
Mehsana (Bombay)	Alluvial soil	152	20·9	1·8	2·9
Pisanganj (Rajasthan)	Red and yellow soil	141	13·2	2·4	4·8
Manavadar (Bombay)	Medium black soil	148	16·8	2·3	4·7
Mhow (M.P.)	—do—	21	14·4	2·3	5·8
Kunihar (H.P.)	Hilly soil	28	11·6	1·8	3·8
Raisinghnagar (Rajasthan)	Desert soil	126	23·5	2·2	4·2
Sumerpur (Rajasthan)	—do—	81	9·4	1·7	2·9
Average of all centres		1,232	16·0	2·5	4·7
		Unirrigated			
Pusa (Bihar)	Calcareous soil of Gangetic basin	60	11·9	1·8	3·5
Kunihar (H.P.)	Hilly soil	120	8·5	1·6	2·3
Hoshangabad (M.P.)	Deep black soil	110	5·8	1·8	2·2
Average of all centres		290	8·8	1·7	2·7

Forms of nitrogenous fertilizers: Experiments with ammonium nitrate on wheat at the Indian Agricultural Research Institute and Bihar reported by Raychaudhuri *et al.* (1955) indicated a 44 to 50 per cent increase in yield over control.

TABLE XXIV. AVERAGE RESPONSE TO APPLICATION OF AMMONIUM SULPHATE IN TRIALS ON CULTIVATORS' FIELDS (IN MD. PER ACRE) IN COMPLEX TRIALS

Centre	Soil type	Yield without nitrogen	Responses to dose of nitrogen/acre	
			20 lb.	40 lb.
	Irrigated			
Pura (U.P.)	Gangetic alluvium	16·4	2·5	3·9
Banaras (U.P.)	,,	11·2	3·4	5·2
Niphad (Bombay)	Medium black soil	11·4	2·6	4·7
Obedullaganj (M.P.)	,,	11·3	4·8	7·0
Paliad (Bombay)	,,	21·6	2·0	2·4
Kota (Rajasthan)	,,	13·6	2·8	3·9
Bhagwai (M.P.)	,,	11·1	2·5	3·4
Average of all centres		14·0	2·9	4·4
	Unirrigated			
Obedullaganj (M.P.)	Medium black soil	7·6	0·3	2·0
Satna	Mixed red and black soil	7·0	1·7	2·0

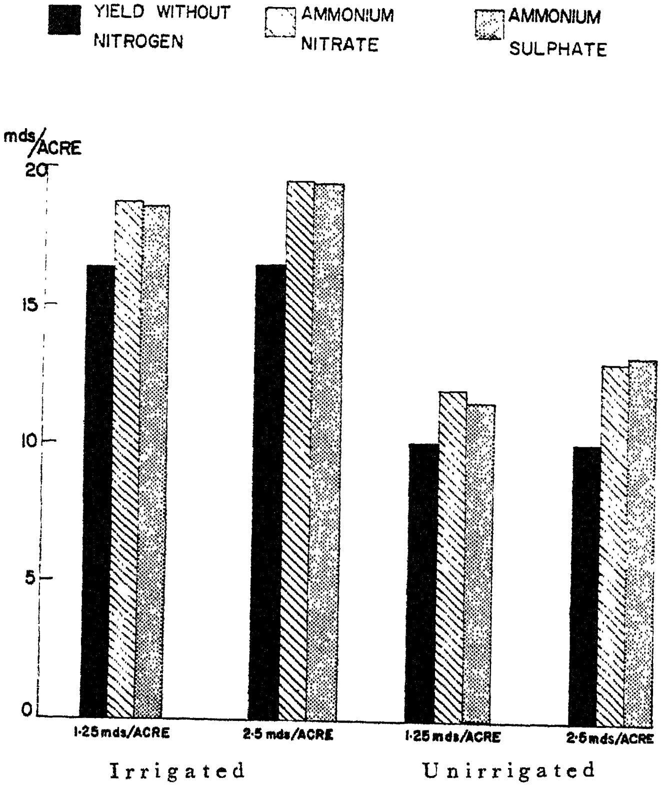
With ammonium sulphate and ammonium nitrate, under both irrigated and unirrigated conditions, response to the two doses of 20 and 40 lb. N were almost similar and either of the two fertilizers could, therefore, be used for the wheat crop (Raheja *et al.*, unpublished). The results are given in Table XXV and Fig. 15.

TABLE XXV. RESPONSE TO THE APPLICATION OF AMMONIUM SULPHATE AND AMMONIUM NITRATE UNDER IRRIGATED AND UNIRRIGATED CONDITIONS

Condition of field	Yield, without addition of nitrogen, in md. per acre	Response in md. per acre			
		Amm. sulphate		Amm. nitrate	
		20 lb. N	40 lb. N	20 lb. N	40 lb. N
Irrigated	16·38	2·28	3·08	2·32	3·15
Unirrigated	10·12	1·39	3·06	1·85	2·84

The average response at both the levels were higher under irrigated conditions. Urea and ammonium sulphate, each applied at the levels of 20 and 40 lb. N per acre, were compared at centres located in alluvial and medium black soil areas. On an average, the responses to urea were low compared to those to ammonium sulphate, the average responses at 20 and 40 lb. N level being 2·8 and 4·3 md. per acre for ammonium sulphate and 2·1 and 3·7 md. per acre for urea.

The comparative efficiencies of ammonium chloride and ammonium sulphate-nitrate against ammonium sulphate were investigated at four centres. The results are given in Table XXVI.



Irrigated Unirrigated

FIG. 15. Response of wheat to ammonium sulphate and ammonium nitrate at different levels (20 and 40 lb./acre) of nitrogen

At Pura ammonium chloride was superior to both ammonium sulphate and ammonium sulphate-nitrate at the lower dosages. At Kota, where the yields of wheat were comparatively high without nitrogen, there was no response to any of the fertilizers. There was no indication of differential response to the various nitrogenous fertilizers at other centres.

The overall results in general from these trials indicate that various nitrogenous fertilizers have about the same efficiency, when applied at the same level of nitrogen. However, there are indications that in certain areas one fertilizer is superior to the other. But, sufficient data are not available to demarcate zones for making recommendations for the use of particular fertilizers.

Responses to different levels of nitrogen were studied at ten centres under irrigated conditions and at two centres under unirrigated conditions, under the Model Agronomic Experiments Scheme sponsored by the Indian Council of Agricultural Research. The responses, standardized to 20 and 40 lb. N per acre, are presented in Table XXVII.

TABLE XXVI. RESPONSE IN MD. PER ACRE TO DIFFERENT SOURCES OF NITROGEN AT DIFFERENT LEVELS OF APPLICATION

Centre	Soil type	Dose of nitrogen (lb./acre)	Response in md./acre			Yield without nitrogen (md./acre)
			Amm. sulphate	Amm. chloride	Amm. sul.-nitrate	
Pura (U.P.)						
	Gangetic alluvium	20	2·9	4·3	1·1	
		40	1·7	3·8	0·2	15·1
		60	3·6	3·1	2·7	
	Average		2·7	3·7	1·2	
Banaras (U.P.)						
	Gangetic alluvium	20	1·6	1·7	1·7	
		40	2·8	5·6	1·6	9·0
		60	6·1	6·0	6·2	
	Average		3·5	4·4	3·2	
Niphad (Bombay)						
	Medium black soil	20	5·0	3·0	4·4	
		40	6·4	6·1	8·0	10·1
		60	7·7	8·4	7·3	
	Average		6·4	5·8	6·6	
Kota (Rajasthan)						
	Medium black soil	20	1·4	1·0	0·1	
		40	2·2	0·6	0·7	18·1
		60	0·8	0·3	0·1	
	Average		1·5	0·6	0·3	

The average response to 20 lb. N per acre, under irrigated conditions, was 3·1 md. The response was very high at Lakhmapur, Obedullaganj and Varanasi, while moderate responses were obtained at Bhagwai, Powerkheda, Sriganganagar and Nasirpur. Under unirrigated conditions, the yield without addition of nitrogen, as well as the response to various levels of nitrogen application, were low as soil moisture was the limiting factor.

Time of application of nitrogenous fertilizers: Effect of the time of application of the three nitrogenous fertilizers, namely, ammonium sulphate, ammonium nitrate and urea was studied at seven centres under the Model Agronomic Experiments. The responses in respect of the three fertilizers are presented in Table XXVIII.

TABLE XXVII. RESPONSE OF WHEAT TO DIFFERENT LEVELS OF NITROGEN (Averaged over all the treatments)

State	Experimental centre	Soil	Yield without nitrogen (md./acre)	Response (md./acre) to doses of nitrogen	
				20 lb.	40 lb.
		Irrigated			
Bombay	1. Lakhmapur	Medium black	14·0	4·4	6·4
	2. Umrala	,,	20·4	1·1	0·5
Madhya Pradesh	3. Bhagwai	,,	10·6	2·5	4·3
	4. Obedullaganj	,,	18·2	7·5	10·9
	5. Powerkheda	Deep black	9·9	3·1	4·5
Rajasthan	6. Sriganganagar	Desert soil	18·4	2·3	3·0
Punjab	7. Nasirpur	Indus alluvium	19·9	3·2	3·9
	8. Sirsa	,,	22·4	1·4	1·5
Uttar Pradesh	9. Pura	Gangetic alluvium	20·8	–0·6	–1·4
	10. Varanasi	,,	6·0	6·0	8·6
Average over all centres			15·0	3·1	4·2
		Unirrigated			
Madhya Pradesh	1. Powerkheda	Deep black	6·4	1·8	2·6
	2. Ujjain	Medium black	4·4	0·6	0·3
Average over all centres			5·4	1·2	1·5

On an average, the application of 20 lb. nitrogen per acre at sowing, or at first irrigation, or half at sowing and half at first irrigation, increased wheat yield by 4·1, 3·1 and 3·5 md. per acre respectively. Thus, application at sowing resulted in better response than application at first irrigation or application in split doses.

Response to organic manures. The value of organic manures lies both in the plant nutrients they contain and the function they perform in improving the soil structure. Cultivation of soil is usually accompanied by loss of organic matter which is quite rapid under tropical conditions. Of the organic manures, farmyard manure, compost and green manure are more commonly applied. Oilcakes are also used to some extent.

The response to two levels of farmyard manure was studied at six centres under irrigated and unirrigated conditions. The results are given in Table XXIX and Fig. 16.

TABLE XXVIII. RESPONSE IN MD. PER ACRE TO DIFFERENT TIMES OF APPLICATION OF NITROGEN
(Basal dose of 20 lb. P_2O_5 per acre)

State	Experimental centre	Soil	Control yield (md./acre)	Level of N (lb./acre)	Response to nitrogen applied at		
					Sowing	First irrigation	½ at sowing+½ at 1st irrigation
Bombay	Lakhmapur	Medium black	12·0	20	5·5	4·6	5·6
				40	5·6	6·1	7·6
				Mean	5·6	5·4	6·6
Madhya Pradesh	Bhagwai	,,	8·9	20	1·7	2·0	2·8
				40	5·3	3·9	3·8
				Mean	3·5	2·9	3·3
	Obedullaganj	,,	14·0	20	6·0	4·9	4·8
				40	7·9	6·2	7·0
				Mean	7·0	5·6	5·9
Punjab	Nasirpur	Indus alluvium	24·7	20	6·0	4·9	4·8
				40	7·9	6·2	7·0
				Mean	7·0	5·6	5·9
Uttar Pradesh	Pura	Gangetic alluvium	21·9	20	4·1	0·1	1·0
				40	2·0	1·9	0·6
				Mean	3·1	1·0	0·8
	Varanasi	,,	6·1	20	5·2	4·6	5·2
				40	8·0	6·4	8·0
				Mean	6·6	5·5	6·6

Data (given in Table XXIX) show that the immediate response to the addition of F.Y.M. has been generally low.

Sundara Rao and Ghosh (1952), reviewing the results of a large number of manurial experiments, stated that green-manuring is in no way inferior to the application of nitrogenous fertilizers. The response in the yield of wheat, under irrigated conditions, varied from 16 to 36 per cent.

The results of experiments carried out with organic manures, till 1953, have been compiled by Acharya (1955). These are summarized in Table XXX.

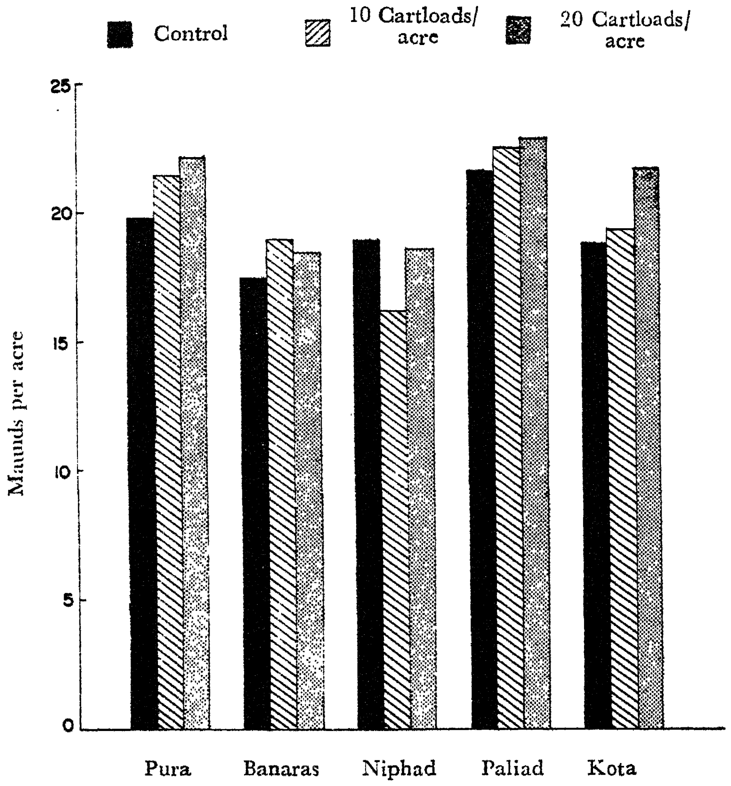


FIG. 16. Response of wheat (in md./acre) to farmyard manure (irrigated crop)

TABLE XXIX. RESPONSE OF WHEAT IN MD. PER ACRE TO FARMYARD MANURE

Centre	Soil	Control	Response to doses of farmyard manure	
			10 cart-loads/acre	20 cart-loads/acre
	Irrigated			
Pura (U.P.)	Gangetic alluvium	19·8	1·6	2·3
Banaras (U.P.)	,,	17·4	1·5	1·0
Niphad (Bombay)	Medium black soil	18·9	2·8	0·4
Paliad (Bombay)	,,	21·5	0·9	1·4
Kota (Rajasthan)	,,	18·7	0·6	2·9
	Unirrigated			
Satna (M.P.)	Mixed red and black soil	7·0	0·2	0·3

TABLE XXX. RESULTS OF ORGANIC MANURIAL TRIALS CONDUCTED UP TO 1953

State	Experimental centre	Soil	Dosage of manure per acre	Yield increase in md.	Remarks
Bihar	Pusa	Calcareous soil of Gangetic basin	Rape cake (20 lb. N)	2·81	Irrigated
			Cattleshed manure 4,000 lb. (20 lb. N)	4·25	,,
			Cattleshed manure 8,000 lb. (40 lb. N)	7·50	,,
Madhya Pradesh	Nagpur	Medium black	Cattle dung (40 lb. N)	5·25	,,
	Chindwara	,,	*Karanj* cake (20 lb. N)	1·90	Unirrigated
	Jabbalpur	Deep black	*Til* cake (15 lb. N)	2·00	Irrigated
	Powerkheda	,,	Cattle dung (40 lb. N)	2·40	Unirrigated
	,,	,,	Castor cake (30 lb. N)	2·00	,,
	Labhandi	Red and yellow soils	Castor cake (30 lb. N)	4·37	Irrigated
	Different centres (8 Trials)		Cattledung (10 lb.N)+Ammonium sulphate (10 lb. N)	1·67	,,
	,,		Oilcake (10 lb. N)+Ammonium sulphate (10 lb.N)	2·40	,,
	Indore	Deep black	Groundnut cake (40 lb. N drilled before manuring)	2·87	,,
Madras	Coimbatore	Mixed red and black	Cattle manure (50 lb. N)	5·40	,,
Punjab	Gurdaspur	Indus alluvium	Cattle manure (50 lb. N)	1·40	Unirrigated
	Hansi	,,	Castor cake (75 lb. N)	4·50	Irrigated
			Castor cake (33 lb. N)	2·87	,,
Uttar Pradesh	Pratapgarh	Gangetic alluvium	*Mahua* cake (120 lb. N)	4·00	,,
		,,	Castor cake (82 lb. N)	7·50	,,
		,,	*Neem* cake (120 lb. N)	5·60	,,
	Kanpur	,,	Cattleshed manure 8,000 lb. (40 lb. N)	3·35	Unirrigated
			Cattleshed manure 8,000 lb. (40 lb. N)	6·56	Irrigated

The responses are higher with oilcakes than with farmyard manure per unit of nitrogen. Responses are better under irrigated than under unirrigated conditions.

In long-term experiments, conducted at the Agricultural Research Institute, Karnal (Punjab), the relative efficiency of farmyard manure was compared with that of ammonium sulphate. The results, reported by Relwani and Ganguly (1958), are summarized in Table XXXI.

TABLE XXXI. COMPARISON OF AMMONIUM SULPHATE AND FARMYARD MANURE

Source of N	Ammonium sulphate		Farmyard manure	
Quantity applied (md./acre)	1·25	2·50	200·00	400·00
N (lb./acre)	20	40	80	160
Response to nitrogen, wheat yield (md./acre)	25·36	27·92	25·65	25·75

These data show that ammonium sulphate is about four times as efficient as farmyard manure on the basis of nitrogen content as far as immediate response is concerned. The relative responses, in terms of grain yield, are 4 lb. with farmyard manure and 12 lb. with ammonium sulphate, when applied on equivalent nitrogen basis.

Experiments with phosphatic fertilizers. Under the Fertilizers Use Project, a number of trials were conducted in complex experiments using triple superphosphate. The results are presented in Table XXXII.

TABLE XXXII. AVERAGE RESPONSE OF WHEAT IN MD. PER ACRE TO SUPERPHOSPHATE

Centre	Soil type	Yield without P_2O_5	Response to phosphate	
			20 lb. P_2O_5	40 lb. P_2O_5
		Irrigated		
Pura (U.P.)	Gangetic alluvium	15·8	3·8	4·3
Banaras (U.P.)	—do—	13·7	0·8	1·2
Niphad (Bombay)	Medium black	12·9	0·4	1·3
Obedullaganj (M.P.)	—do—	13·8	0·8	2·2
Paliad (Bombay)	—do—	22·1	0·8	1·6
Kota (Rajasthan)	—do—	15·6	0·3	1·1
Bhagwai (M.P.)	—do—	8·0	6·6	9·1
Average		14·9	1·7	3·0
		Unirrigated		
Obedullaganj (M.P.)	Medium black	8·1	0·2	1·1
Satna (M.P.)	Mixed red and black	6·6	1·9	3·2
Average		7·8	1·0	2·2

The mean response to phosphorus at 20 lb. P_2O_5 per acre was 1·7 md. and with the increase in the level of phosphorus to 40 lb. an additional response of 1·3 md. per acre was obtained. The response was very high at Bhagwai in Madhya Pradesh. The results indicated that response to application of phosphorus is, in general, considerably lower than the response to nitrogen and is restricted to particular areas.

From the results obtained it does not appear possible to relate the response to phosphorus with the soil type.

Phosphorus in the form of triple superphosphate was also tried at the levels of 20 and 40 lb. P_2O_5 per acre over a basal dressing of nitrogen in simple trials in cultivators' fields. Results are presented in Table XXXIII.

TABLE XXXIII. AVERAGE RESPONSE IN MD. PER ACRE TO DOSES OF PHOSPHORUS IN CULTIVATORS' FIELDS FROM 1953-54 TO 1955-56

(Basal dressing 20 lb. N as amm. sulphate)

Centre	Yield without P_2O_5	Response to doses of phosphorus	
		20 lb. P_2O_5/acre	40 lb. P_2O_5/acre
	Irrigated		
Nawanshahr	21·1	1·9	3·3
Nilokheri	18·9	0·9	1·6
Bhudan	22·5	1·3	1·5
Alipur	20·7	1·8	3·3
Mehsana	23·6	0·9	1·9
Pisanganj	13·4	0·8	1·7
Manavadar	18·9	0·4	1·2
Kunihar	13·8	0·9	1·6
Raisinghnagar	22·2	2·5	4·7
Sumerpur	11·9	0·4	0·9
Average over all centres	18·7	1·1	2·2
	Unirrigated		
Pusa	14·2	0·2	1·4
Kunihar	14·9	0·6	1·2
Hoshangabad	5·6	0·3	0·6
Average over all centres	11·6	0·4	1·1

The responses to phosphorus showed considerable variation within centres. The mean response to 20 lb. P_2O_5 was 1·1 md./acre and with the increase in phosphorus from 20 to 40 lb. P_2O_5 per acre an additional mean response of 1·1 md./acre was obtained. The response to phosphorus was relatively high in the desert soil of Raisinghnagar, in the alluvial soil of Delhi and the grey and brown soils of Nawanshahr.

The results of some typical field experiments conducted in India with superphosphate show increases of 7–16 per cent in the case of irrigated wheat. In the case of unirrigated wheat from a poor and negative response to a high response showing an increase of 93·3 per cent has been obtained. The results are summarized in Table XXXIV.

TABLE XXXIV. RESPONSE OF WHEAT TO SUPERPHOSPHATE (Raychaudhuri and Chandnani, 1958)

Centre	Soil	Treatment	Yield in lb./acre	% increase
Pusa (Bihar)	Calcareous sandy loam	40 lb. P_2O_5/acre	465	93·3
,,	,,	No manure	241	
Coimbatore (Madras)	Wet lands	Super 30 cwt./acre	659	61
,,	,,	No manure	409	
Jullundur (Punjab)	Loam (irrigated)	125 lb. P_2O_5/acre	1,812	−7·2
,,	,,	No manure	1,942	—
Gurdaspur (Punjab)	Alluvium (unirrigated)	56 lb. P_2O_5/acre	1,543	9·5
,,	,,	No manure	1,409	
Aligarh (U.P.)	Loam	18 lb. P_2O_5/acre	1,773	15·6
,,	,,	No manure	1,538	

Preliminary experiments with dicalcium phosphate at the Indian Agricultural Research Institute have indicated that this fertilizer is as good as superphosphate.

Superphosphate and dicalcium phosphate were compared at some of the Community Project Centres. The results are given in Table XXXV.

TABLE XXXV. RESPONSE OF WHEAT (IN MD. PER ACRE) TO SUPERPHOSPHATE AND DICALCIUM PHOSPHATE

Centre	Soil	Superphosphate		Dicalcium phosphate	
		20 lb. P_2O_5	40 lb. P_2O_5	20 lb. P_2O_5	40 lb. P_2O_5
Nawanshahr (Punjab)	Indus alluvium	1·7	2·9	1·2	2·8
Bhadson (Punjab)	,,	0·6	2·5	0·6	1·6
Alipur (Delhi)	Gangetic alluvium	1·1	2·0	1·7	2·1
Pisanganj (Rajasthan)	Red and yellow soil	2·2	3·2	2·9	2·9
Raisinghnagar ,,	Desert soil	2·5	4·7	2·1	2·5
Average over all centres		1·6	3·0	1·7	2·3

There was no real difference in response to the two fertilizers, at either level, except on the desert soil of Raisinghnagar where superphosphate gave a higher response at 40 lb. P_2O_5 level.

Responses to levels of phosphorus were studied at 11 centres under irrigated conditions and at three centres in Madhya Pradesh under unirrigated conditions, where wheat is mainly cultivated on the conserved soil moisture under the Model Agronomic Experiments. The responses from all the experiments were standardized to 20 and 40 lb. P_2O_5 per acre (Table XXXVI).

TABLE XXXVI. AVERAGE RESPONSE OF WHEAT IN MD. PER ACRE TO LEVELS OF PHOSPHORUS

State	Experimental centre	Soil	Yield without P_2O_5 (md./acre)	Response to doses of P_2O_5/acre	
				20 lb.	40 lb.
		Irrigated			
Bombay	1. Lakhmapur	Medium black	19·4	0·5	0·8
	2. Umrala	,,	19·0	2·4	3·5
Madhya Pradesh	1. Bhagwai	,,	14·0	1·4	0·8
	2. Obedullaganj	,,	25·1	0·7	1·2
	3. Powerkheda	Deep black	9·3	3·6	5·3
Orissa	1. Barpalli	Red loam	5·2	1·2	5·5
Rajasthan	1. Sriganganagar	Desert soil	19·3	0·6	0·6
Punjab	1. Nasirpur	Indus alluvium	20·2	0·0	0·5
	2. Sirsa	,,	21·3	−0·1	0·6
Uttar Pradesh	1. Pura	Gangetic alluvium	15·0	6·9	8·0
	2. Varanasi	,,	6·3	0·5	0·6
	Average over all centres		15·2	1·6	2·6
		Unirrigated			
Madhya Pradesh	1. Powerkheda	Deep black	8·2	0·0	0·0
	2. Reura Farm	Mixed red and black	5·1	8·8	10·3
	3. Ujjain	Medium black	8·5	0·8	−0·7
	Average over all centres		7·3	3·2	3·2

On an average, application of 20 lb. P_2O_5 per acre increased the wheat yield by 1·6 md. per acre under irrigated conditions. As recorded for nitrogen, response to doses of phosphorus was higher under irrigated conditions as compared to unirrigated conditions when these experiments were conducted at the same place. Under unirrigated conditions the yields without phosphorus were generally low; at Reura (M.P.) the response to P_2O_5 was very high.

Increase in the level of phosphorus from 20 to 40 lb. P_2O_5 per acre gave significant increase in response at the Pura, Barpalli and Powerkheda centres only.

Placement of phosphatic fertilizers: For deriving the maximum benefit out of the fertilizer, it is necessary that an efficient and rational method of application of phosphate is followed. Broadcasting on the soil surface is usually less desirable than placing deeper in the soil where it is in a better position in relation to the plant roots. Three methods of application were compared at six centres under irrigated and unirrigated conditions. At Pura and Banaras there was no significant difference with different methods of application. At Bhagwai where a larger response to phosphorus was obtained, localized application proved better. At Satna, under unirrigated conditions, the response was lower in the case of the broadcast treatment as compared to placement of superphosphate (Table XXXVII).

TABLE XXXVII. DIFFERENTIAL RESPONSE TO METHODS OF APPLICATION OF PHOSPHATE IN MD. PER ACRE

Centre	Soil type	Yield without phosphate	Average response to 20 and 40 lb. P_2O_5 per acre		
			Broadcasting	Band placement	Placement 2½" below seed
		Irrigated			
Pura (U.P.)	Gangetic alluvium soil	11·8	6·2	0·5	5·1
Banaras (U.P.)	,,	18·2	2·6	1·7	2·1
Paliad (Bombay)	Medium black soil	20·1	1·8	1·6	0·2
Kotah (Rajasthan)	,,	17·9	0·3	0·8	0·8
Bhagwai (M.P.)	,,	7·9	7·9	9·7	10·3
		Unirrigated			
Satna (M.P.)	Mixed red and black soil	4·2	3·6	5·0	5·2

Combined phosphatic and nitrogenous fertilizers

Ammonium phosphate: Ammonium phosphate fertilizer is available as mono-ammonium phosphate and di-ammonium phosphate. Commercial mono-ammonium phosphate mixed with various amounts of ammonium sulphate or other fertilizers to give different N to P ratios is available in two grades, one containing 10·7 to 11·0 per cent nitrogen and 48 per cent P_2O_5 and the other containing 10 per cent nitrogen and 20 per cent P_2O_5. This, being a combined nitrogen and phosphatic fertilizer, is likely to find greater use in areas in which phosphate requirement is relatively high. Results of complex experiments under the Indo-U.S. Project on Soil Fertility and Fertilizer Use conducted at various centres are given in Table XXXVIII.

TABLE XXXVIII. RELATIVE RESPONSE IN MD. PER ACRE TO SUPERPHOSPHATE AND AMMONIUM PHOSPHATE (Basal dressing of 20 lb. N per acre)

Centre	Soil type	Yield without P_2O_5	Response to superphosphate		Response to ammonium phosphate	
			20 lb. P_2O_5	40 lb. P_2O_5	20 lb. P_2O_5	40 lb. P_2O_5
		Irrigated				
Pura (U.P.)	Gangetic alluvium	11·8	5·6	5·4	4·9	6·0
Banaras (U.P.)	,,	18·2	2·4	2·0	2·5	2·3
Paliad (Bombay)	Medium black soil	20·1	0·0	2·6	1·2	0·4
Kota (Rajasthan)	,,	17·9	1·3	0·8	0·8	0·3
Bhagwai (M.P.)	,,	7·9	8·1	11·8	8·3	18·0
		Unirrigated				
Satna (M.P.)	Mixed red and black soil	4·5	5·9	8·7	5·9	6·7

Responses to phosphate in both forms were obtained at Pura, Varanasi, Bhagwai and Satna. Except at Satna, there was no significant difference in response to two fertilizers. At Satna, superphosphate indicated better response at the higher level of applications.

Nitrophosphate: This fertilizer contains 20·5 per cent N and 20 per cent P_2O_5. The results of simple experiments in cultivators' fields are given in Table XXXIX.

TABLE XXXIX. RESPONSE IN MD. PER ACRE TO DIFFERENT LEVELS OF SUPERPHOSPHATE AND NITROPHOS (Basal dressing of 40 lb. N per acre as ammonium sulphate)

Centre	Soil type	Response to superphosphate		Response to nitrophosphate	
		20 lb. P_2O_5	40 lb. P_2O_5	20 lb. P_2O_5	40 lb. P_2O_5
		Irrigated			
Nawanshahr (Punjab)	Indus alluvium	2·0	1·6	0·6	1·6
Bhadson (Punjab)	,,	1·2	0·9	1·3	0·2
Pisanganj (Rajasthan)	Red and yellow soil	0·9	2·3	3·9	3·1
Manavadar (Bombay)	Medium black soil	0·3	2·5	0·5	1·4
Raisinghnagar (Rajasthan)	Desert soil	4·1	9·4	1·9	0·9

The difference in response to superphosphate and nitrophosphate varied widely in the several centres. At Raisinghnagar, superphosphate gave very high response as compared to nitrophos while at Pisanganj nitrophosphate indicated better response.

Mixed nitrogen and phosphate fertilizers: The experimental evidence in India so far shows that nitrogenous fertilizers constitute a major need for Indian soils and phosphate as a supplement to nitrogen would be very useful in some tracts. The response of wheat to various combinations of nitrogen and phosphorus, applied in the form of ammonium sulphate and triple superphosphate, respectively, are given in Table XL and Fig. 17.

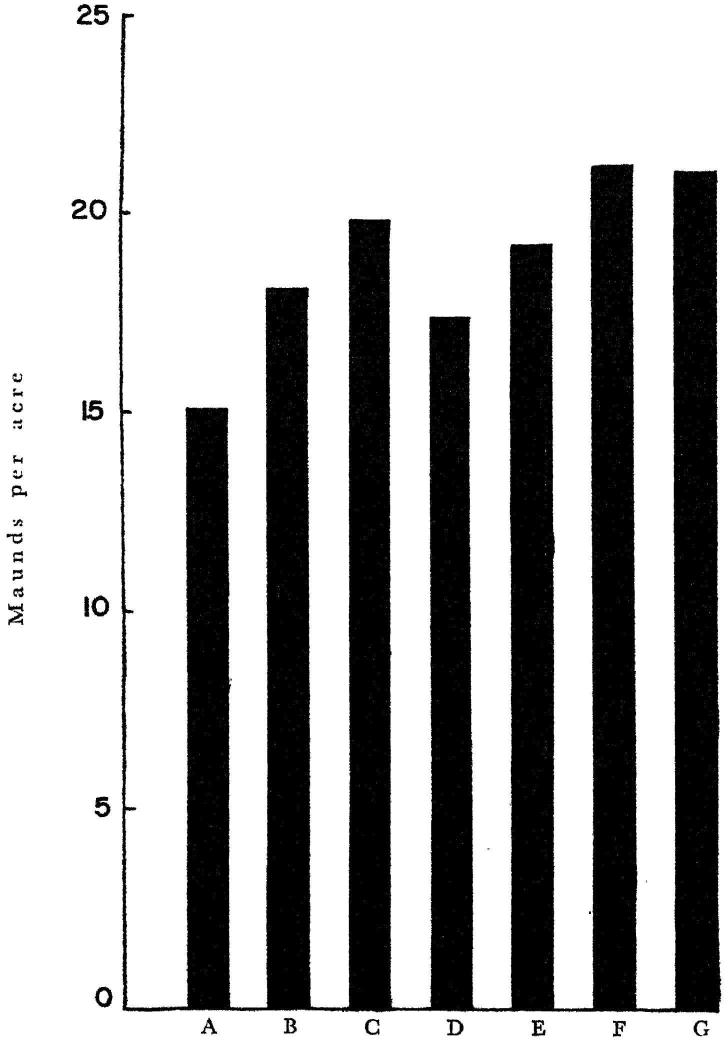


FIG. 17. Yield of wheat (in md./acre) to nitrogen and phosphorus applied in combination (irrigated crop)
A, control; B, 20 lb. N/acre; C, 40 lb. N/acre; D, 20 lb. P_2O_5/acre; E, 20 lb. N+20 lb. P_2O_5/acre; F, 40 lb. N+20 lb. P_2O_5/acre; G, 20 lb. N+40 lb. P_2O_5/acre.

TABLE XL. AVERAGE RESPONSE OF WHEAT IN MD. PER ACRE TO NITROGEN AND PHOSPHATE APPLIED IN COMBINATION

	Yield of control	Response					
		20 lb. N/ acre	40 lb. N/ acre	20 lb. P_2O_5/acre	20 lb. N +20 lb. P_2O_5	20 lb. N +40 lb. P_2O_5	40 lb. N +20 lb. P_2O_5
Irrigated	15·1	3·0	4·7	2·3	4·2	5·2	5·9
Unirrigated	8·1	1·7	2·5	1·4	2·6	2·6	4·1

The response to nitrogen and phosphorus applied alone, each at 20 lb. per acre, was 3·0 and 2·3 md. per acre respectively. When 20 lb. N and 20 lb. P_2O_5 were applied in combination, the response was 4·2 md. per acre; maximum response was obtained with the combination of 40 lb. N and 20 lb. P_2O_5. Under unirrigated conditions, the response to all combinations were lower as compared to those under irrigated conditions.

Panse (1959) reported on experiments, on the lines recommended by Dr. A. B. Stewart, on the wheat crop conducted in the states of Bihar, Bhopal, Maharashtra and Gujarat, Punjab and Pepsu. A total of 148 experiments in the three years 1952–53 to 1954–55 were conducted in the Shahabad district of Bihar; during the three years 1953–54 to 1955–56, 157 experiments were conducted in Nasik district, and during 1954–55 to 1955–56, 139 experiments were conducted in the Mehsana district of Gujarat State. Results from these experiments are presented in Table XLI.

TABLE XLI. RESPONSE OF WHEAT TO NITROGEN AND PHOSPHORUS

Centre	Control yield md./acre	Response in md. per acre					
		20 lb. N	40 lb. N	40 lb. P_2O_5	20 lb. N+ 20 lb. P_2O_5	40 lb. N+ 20 lb. P_2O_5	40 lb. N+ 40 lb. P_2O_5
Nasik (Maharashtra)	9·6	1·6	2·7	1·1	3·6	4·5	—
Mehsana (Gujarat)	19·4	2·9	5·8	1·3	5·1	8·3	—
Shahabad (Bihar)	6·8	—	4·1	—	—	—	6·8

The results given in Table XLI indicate that a response of 4·1 md. per acre was obtained to the application of 40 lb. nitrogen per acre in Bihar State. The additional response to the application of 40 lb. P_2O_5 over 40 lb. N was of the order of 2·7 md. per acre. The results from Maharashtra and Gujarat indicate that as the total amount of nitrogen and phosphorus increased, whether applied singly or in combination, the response also increased correspondingly. Responses in Mehsana district were quite high.

Field experiments with potassic fertilizers. The field experiments, so far conducted in India, on wheat indicate that the need for potassium is not felt at the present level of production. At Pusa (Bihar) potassium sulphate at 25 lb. K_2O per acre gave no significant response. NPK treatment gave 147 per cent increase in yield of wheat over control as compared to 138 per cent given by NP.

Under the Indo-U.S. Project on Soil Fertility and Fertilizer Use, potash was extensively tried in simple experiments. The results indicated that in some places like Delhi, in the submontane soils of Himachal Pradesh and desert soils of Raisinghnagar potash gave a moderate response, but in the majority of the centres the response was very low. The average for all the centres in simple trials was 0·7 md. of wheat for 20 lb. of K_2O per acre and with 40 lb. K_2O there was an additional response of 0·8 md. per acre. There was no response to potash, at either level, in the case of complex experiments. The results are given in Tables XLII and XLIII.

TABLE XLII. RESPONSE OF WHEAT IN MD. PER ACRE TO LEVELS OF POTASH IN COMPLEX EXPERIMENTS

Centre	Soil type	Yield without potash	Response to doses of potash/acre	
			20 lb. K_2O	40 lb. K_2O
	Irrigated			
Pura (U.P.)	Gangetic alluvium	20·5	0·6	1·8
Banaras (U.P.)	,,	18·3	0·6	0·3
	Unirrigated			
Satna (M.P.)	Mixed red and black soil	7·4	0·3	0·1

TABLE XLIII. RESPONSE OF WHEAT IN MD. PER ACRE TO LEVELS OF POTASH IN SIMPLE EXPERIMENTS

Centre	Soil type	Yield without potash	Response to doses of potash/acre	
			20 lb. K_2O	40 lb. K_2O
	Irrigated			
Nawanshahr (Punjab)	Indus alluvium	20·4	1·1	2·2
Nilokheri (Punjab)	,,	21·8	0·1	2·5
Bhadson (Punjab)	,,	24·7	0·7	0·5
Alipur (Delhi)	Gangetic alluvium	22·0	2·5	2·8
Mehsana (Bombay)	Alluvium	24·5	0·1	0·5
Pisanganj (Rajasthan)	Red and yellow soils	12·7	0·9	1·6
Kunihar (H.P.)	Hills	13·5	1·2	2·5
Raisinghnagar (Rajasthan)	Desert	20·2	1·6	1·8
Sumerpur (Rajasthan)	,,	13·6	0·8	0·6
	Unirrigated			
Pusa (Bihar)	Calcareous sandy loam	14·4	0·8	2·1
Kunihar (H.P.)	Hilly soils	16·2	1·8	2·6
Hoshangabad (M.P.)	Deep black	6·0	0·3	0·1

It appears from the results that application of potash will have to be made only in restricted areas after carefully ascertaining the response.

Results of 15 experiments conducted prior to 1931 in different states to estimate the response of potash on various soil types, as compiled by Vaidyanathan (1933), are summarized in Table XLIV.

TABLE XLIV. RESPONSE OF WHEAT TO POTASH ON VARIOUS SOIL TYPES

No. of experiments	Soil type/response per acre per lb. K_2O		Mean response in lb.	Mean response of positive value in lb.
	Alluvial	Laterite and red		
15	−3·0	−0·4(8)	−1·61	2·8(6)

From the results it is clear that a great proportion of experiments conducted till 1931 showed negative response to potash on alluvium, laterite and red soils. However, in six out of 15 experiments, response to potash was of positive nature, giving an average response of 2·8 lb. of wheat per lb. of K_2O.

Panse *et al.* (1947) summarized the results of 806 manurial trials conducted on wheat at various agricultural experimental stations. They observed that under irrigated conditions, a response of 3 to 5 lb. per lb. of K_2O was obtained at Saugor and Nagpur in Madhya Pradesh to applications of potash at the rate of 30 to 40 lb. K_2O per acre in the presence of nitrogen and phosphate, but in Bombay there was either no positive response or there was even a depression in yield. In some other trials at Nagpur, Labhandi and Powerkheda, an average response of 10·0 lb. per lb. of N and 3·3 lb. per lb. of K_2O was obtained.

Under the Model Agronomic Experiments Scheme, response to potash was studied at three centres. The results are summarized in Table XLV.

TABLE XLV. AVERAGE RESPONSE OF WHEAT IN MD. PER ACRE TO LEVELS OF POTASH

State	Experimental centre	Soil	Yield without potash	Response to doses of K_2O/acre	
				20 lb.	40 lb.
		Irrigated			
Punjab	Nasirpur	Indus alluvium	20·9	−0·9	−0·8
Rajasthan	Sriganganagar	Desert soil	15·0	−0·6	0·1
		Unirrigated			
Madhya Pradesh	Powerkheda	Deep black	8·4	−0·3	−0·3

The responses to potash applied at 20 and 40 lb. K_2O per acre were mostly negative, showing thereby that the soils cropped to wheat in the Punjab, Rajasthan and Madhya Pradesh contain adequate amounts of K_2O for normal yields of wheat.

MICRONUTRIENTS

It is now clearly established that in addition to major nutrients, plants also need comparatively small quantities of other elements like manganese, zinc, copper, boron and molybdenum. Supply of these elements, below or above certain limits, is reflected in the growth of plants by the appearance of characteristic symptoms and this may ultimately lead to a decrease in yield.

In India, deficiencies of these elements in the soils and their effect on wheat have not been widely studied. In pot experiments at Poona, copper has been found to increase the yield of wheat.

In general, deficiencies of trace elements, e.g., boron and copper, have been found to exist in calcareous soils, soils of high pH, highly leached sandy soils and peaty soils.

The deficiencies of these microelements is usually due to low availability rather than an absolute lack of the element. Sprays are often used as a temporary corrective measure (Ignatieff, 1949). Boron and copper deficiency could be corrected by applications of 4–28 lb. of borax and copper sulphate per acre applied broadcast or mixed with fertilizers.

Sadaphal and Das (1956a, b) reported that micronutrients like copper, manganese, zinc and magnesium,? whether applied singly or in combination to Delhi soils, significantly increased the yield of wheat, the maximum increase being with manganese. The results of a field trial with application of 5 lb. per acre of copper and zinc and 10 lb. per acre of manganese and magnesium are presented in Table XLVI.

TABLE XLVI. EFFECT OF APPLICATION OF MICRONUTRIENTS ON YIELD OF WHEAT

Treatment	Yield of wheat grain (lb./acre)
NPK*	1,428
NPK + copper	1,665
NPK + manganese	1,861
NPK + zinc	1,599
NPK + magnesium	1,726
NPK + Cu, Mo, Zn, Mg	1,805

*N—30 lb.; P_2O_5—50 lb.; K_2O—20 lb./acre.

MANURES AND FERTILIZERS IN RELATION TO SOILS

Any major soil group has a number of soil series and types. From the different responses to manures and fertilizers, therefore, only some very broad conclusions can be drawn, as discussed below.

1. Gangetic alluvium of U.P. and Bihar. (a) Since 1949, Simple Fertilizer Trials on Cultivators' Fields have been carried out in 19 districts of Uttar Pradesh by the Soil Survey Organization. These trials were taken up with the sole object of assessing the nutrient requirements of the major food crops in the different soil types found in the area.

As reported by Agarwal and Gangwar (1959), out of the 19 districts studied 18 gave medium to very high response with nitrogen, consisting of over 2 md. of extra wheat grain per acre. Allahabad was the only exception where the response was found to be less than 2 md. per acre. Seven districts, viz., Etah, Mirzapur, Jhansi, Bareilly, Kanpur, Farrukhabad and Ghazipur, fell in the medium response class; Manipuri, Hamirpur, Lucknow, Lakhimpur Kheri and Ballia had high responses, and six districts, viz., Varanasi, Fatehpur, Bouda, Agra, Aligarh and Jalaun, came in the very high response class, showing over 4 md. of extra yield per acre. The additional crop yields due to phosphate application over nitrogen show that except for the two districts of Farrukhabad and Jhansi, the rest gave more than 1 md. of extra grain per acre.

(b) About five thousand experiments were conducted on wheat crop from 1948 to 1956 in Bihar State. As reported by Panse (1959), the average response to 30 lb. N per acre for the whole State and for the entire period of experimentation was about 3·4 md. per acre. Low response was obtained in Ranchi district and the highest response of 4·9 md. per acre was obtained in the Hazaribagh district. Shahabad, Gaya, Manbhoom and Patna are other districts where the response to 30 lb. N was more than 4 md. per acre. Clayey soils of gneissic origin gave the best results, with loamy alluvial soils coming next. Gneissic soils, on the whole, seem to be as good as alluvial soils in regard to response of wheat to nitrogen.

The average response to 40 lb. P_2O_5 per acre for the whole State was about 3·2 md. per acre. Districts Ranchi and Palamau seem to be below average in this respect. Singhbhum presented the highest response of about 5–6 md. per acre. Alluvial and gneissic soils do not seem to differ in response. Very high responses on other soils have been obtained but these are based on relatively small number of experiments.

The average response to 40 lb. K_2O per acre for the whole State works out to nearly 1·4 md. per acre. The responses in alluvial and gneissic soils were nearly of the same order. The highest response of 3·5 md. per acre was obtained on clay soils of unspecified origin. The results were, however, based on only 29 experiments. Responses to both nitrogen and phosphate were generally highest on sandy clay types of soils.

2. Indus alluvium of the Punjab. A combination of nitrogen and phosphate (40 lb. N+20 lb. P_2O_5) appeared to have given the maximum increase in yield of wheat (6·7 md. per acre). Nitrogen alone at the rate of 20 and 40 lb. per acre increased the yield of wheat by 3·3 and 5·7 md. respectively; phosphate at the rate of 20 and 40 lb. P_2O_5 per acre increased the yield by 1·5 and 2·4 md. respectively. The average increase in the yield due to potash was not much, although in certain areas it was quite appreciable. The average response with 20 and 40 lb. K_2O was 0·75 md. per acre respectively.

3. Black soils of Madhya Pradesh, Bombay and Mysore states. On black soils, under irrigated conditions, wheat responded well to combination of nitrogen and phosphate, the average response being 5·7 md. per acre with 40 lb. N and 20 lb. P_2O_5. Average response to nitrogen at 20 and 40 lb. levels was 2·6 and 4·6 md. per acre respectively. These responses are comparatively less than those obtained on the soils of Indus alluvium of the Punjab, but there is not much difference as regards responses to phosphate. Under unirrigated conditions responses to nitrogen and phosphorus are comparatively much less.

4. **Hill soils of the Siwaliks and the Himalayas.** On these soils also, a combination of nitrogen and phosphate gave the maximum response (4 md. per acre with 40 lb. N and 20 lb. P_2O_5). The response to nitrogen at 20 and 40 lb. per acre was 1·8 and 3·8 md. respectively; phosphate gave a response of 0·9 and 1·6 md. with 20 and 40 lb. P_2O_5 respectively. On the whole, on these types of soils, the responses are comparatively less than on the soils of other regions. There is not much difference in responses at Kunihar under irrigated and unirrigated conditions.

5. **Desert soils under irrigated conditions**). The maximum response was obtained with the application of nitrogen and phosphate in combination. The average response was 5·3 md. per acre with 40 lb. N and 20 lb. P_2O_5 in combination. The responses to nitrogen alone were also good, the average being 2·1 and 4·0 md. per acre with 20 and 40 lb. N respectively.

While the results of numerous field experiments have clearly shown that increased yields are obtained by the use of nitrogenous fertilizers alone on almost all types of soils under irrigated conditions, a supplementary dose of phosphate on many of the soils has produced a sufficient additional response to give an economic return for the application of phosphatic fertilizers. Where the response to fertilizers has not been obtained or is not adequate, there is a need for examining specific requirements by soil analysis or field experiments to provide a guide for the judicious use of fertilizers. Jain *et al.* (1959), after conducting some experiments at Jaipur, have concluded that on desert soils nitrogen was found to be the limiting factor for increased wheat production, while the effect of phosphate was negligible. The application of 20 and 40 lb. N in the form of ammonium sulphate increased wheat yield by 4·97 and 8·78 md. per acre, respectively, and superphosphate at the rate of 25 and 40 lb. P_2O_5 increased wheat yield by 0·15 and 0·36 md. per acre respectively. When N and P_2O_5 were applied in combination the responses are of the same order as those obtained with N alone.

FOLIAR APPLICATION OF FERTILIZERS FOR INCREASING YIELD OF WHEAT

Much of the biological activity of soils and plants is associated with ionic exchange complexes. This exchange can take place through the foliar membrane as well as through the root cell structure. The plant sap moves by capillary action to the surface of leaves and evaporation of water takes place from the foliar cells. Plant nutrients in the right proportion can be applied to the leaves and, therefore, the question of absorption of nutrient through the leaves and utilization of plant nutrient through foliar fertilization is important.

Sadaphal and Das (1956a), while reporting the results of spraying urea on wheat, stated that spraying at a concentration as low as 1 per cent in the absence of the basal dressing of NPK, resulted in a significant increase in the yield of wheat. Results of their field experiments are presented in Table XLVII.

Sadaphal and Das (1956b) tried the foliar applications of micronutrients. They reported that, while soil application of manganese was more efficient than foliar application, zinc showed better results when sprayed on the leaves. Generally, the effect of foliar application of micronutrients was noticed in increasing the yield of wheat grains. It thus appears that foliar sprays can be effectively utilized as a supplementary method of fertilization of wheat.

Table XLVII. Effect of spraying urea on wheat

Treatment	Yield of wheat (lb./acre)
1 per cent urea sprayed once (4·25 lb. N/acre)	1,814
1 per cent urea sprayed twice (8·5 lb. N/acre)	1,733
2 per cent urea sprayed once (8·5 N/acre)	1,850
2 per cent urea sprayed twice (17·0 lb. N/acre)	1,797
No spray	1,531

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XIV

AGRONOMY—CULTURAL PRACTICES

The cultural practices adopted for wheat cultivation vary from place to place, depending upon the soil, climate, irrigation facilities and system of cropping. While a comprehensive account of the cultural practices as prevalent in the various parts of the country is to be found in *Wheat in India* by Howard and Howard (1909), results of more recent investigations on this aspect are reported in this chapter.

Preparatory cultivation. As a *barani* crop, wheat grows best on deep black and medium black soils found in central India, Ahmedabad, East Khandesh, Surat, Baroda, Dharwar and Ahmednagar districts of Bombay State. For irrigated wheat, well-drained, light alluvial loams are more suitable than lighter or heavier soils of the Indo-Gangetic Basin.

The number of ploughings required to secure proper tilth for wheat varies from place to place, but generally the soil is ploughed once to a depth of four to five inches with the onset of rains. This is followed by frequent cultivations or *bakharing* to suppress the growth of weeds. Cultivations during rainy season also keep the land open for absorption of rain water and create a mulch which prevents the evaporation of soil moisture from the layers below. Evidently this practice is especially important in the case of the rainfed crop. Whenever *kharif* crops are taken prior to wheat, the stubbles are ploughed up soon after the harvest of the *kharif* crop. Normally it requires one soil inversion with a soil-turning plough and three to four cultivations with the *desi* plough or cultivator to prepare the land for sowing of wheat.

A number of investigations have been conducted on depth and number of ploughings in the Punjab, Delhi, Madhya Pradesh and Bombay. Experiments were conducted on medium black soil at Arnej (Bombay State) from 1951–52 to 1954–55 on the effect of one ploughing versus no ploughing combined with two, three, four and five harrowings. The results obtained did not indicate any significant differences in wheat yield due to the various treatments (Argikar and Patil, 1957). Similar results have been obtained for the dry zone of the Deccan and Karnatak from experiments conducted at the Government Dry Farming Research Station, Sholapur (Kanitkar, 1945). Studies conducted to determine the changes brought about by the various tillage operations on the *kerl* soil at Nargund (Bombay State) indicated that there was greater reduction in the 'volume expansion' due to listing* and harrowing than due to ploughings with a mould board or a country plough. Ploughings with both mould board and country plough had an ameliorative effect on the soil. Of the treatments, such as ploughing every year, once in two years and once in three years, tested at the Agricultural Research Station, Dharwar, in the Mysore State, deep ploughing every third year was found to be more economical than ploughing every year or in alternate years (Argikar and Patil, 1957).

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*Throwing up raised beds or ridges and furrows with lister (middle buster). Listing is popular in the semi-arid wheat-growing regions of the West. It is not yet in vogue in India.

Working with deep black soil of Narmada Valley, Kalamkar and Ekbote (1954) reported no gain in wheat yield due to frequent hot weather ploughings. The monsoon plough, which inverts the soil, proved to be a superior tillage implement for preliminary cultivation during rains to the country plough or the *bakhar* and cross ploughing with the country plough proved superior to *bakharing* alone. The advantage of using an inversion plough for turning in stubbles on deep black soil has been attributed to better conservation of soil moisture under *barani* conditions. On deep or medium deep black soils which become very hard on drying and develop deep cracks, shallow preparatory tillage with *bakhar* seems to be better than the inversion of soil with monsoon plough.

In the Punjab and Delhi, cultivation experiments have been conducted on grey and brown soils of the Indo-Gangetic Basin. At Gurdaspur, medium standard of cultivation gave the highest yield of wheat (Singh, 1946). To investigate the effect of seed-bed preparation with alternate set of tillage implements on the yield of wheat, an experiment was conducted on sandy loam soil at Karnal from 1942–43 to 1946–47. Results obtained are given in Table XLVIII.

TABLE XLVIII. WHEAT YIELDS AS AFFECTED BY PREPARATION OF LAND WITH VARIOUS TILLAGE IMPLEMENTS (Khan, 1953)

Tillage implements	Yield in md./acre					
	1942–43	1943–44	1944–45	1945–46	1946–47	Average
Plough cultivator and disc	13·72	13·21	9·30	15·80	7·83	11·97
Victory-cum-country plough	10·62	11·91	10·63	18·50	8·93	12·10
Country plough	11·37	10·26	8·29	16·59	7·98	10·90

On the sandy loam soils of Karnal, cultivation with bullock-drawn soil-inversion plough-cum-country plough gave increased yield of wheat over that obtained with tractor-drawn implements or the country plough alone. Experiments conducted on alluvial soils of Delhi indicated no advantage of deep ploughing (deeper than five inches) as is evident from the results of Khan and Mathur (1954) presented in Table XLIX.

Under Delhi conditions it was observed that on lands free from weeds the effect of soil inversion on the yield of wheat was not discernible. Discing did not increase the yield of wheat over other treatments.

At the Indian Agricultural Research Institute, New Delhi, an extensive experiment was conducted on the effect of different number of cultivations on soil tilth and wheat yield (Mathur, 1952; Khan and Majumdar, 1958). The frequencies of cultivation compared were three, six, nine and 12 ploughings with the country plough after a preliminary ploughing with soil-inverting plough (Table L).

TABLE XLIX. EFFECT OF DEPTH OF CULTIVATION ON THE YIELD OF WHEAT ON ALLUVIAL SOILS OF DELHI

Cultural treatments	Yield in md./acre		
	1949–50	1950–51	Mean
9″–10″ deep ploughing with tractor-drawn soil-inversion plough	26·29	37·44	31·86
5″ deep ploughing with soil-inversion plough	32·45	39·97	36·21
4″–5″ deep ploughing with country plough	34·00	40·23	37·11
Tractor discing to a depth of 4″	32·99	37·16	35·08

TABLE L. YIELD OF WHEAT IN MD. PER ACRE AS AFFECTED BY FREQUENCY OF CULTIVATION

Treatments (ploughings)	Years of experimentation				Mean
	1950–51	1951–52	1952–53	1953–54	
Three	14·57	4·58	18·13	10·42	11·92
Six	20·94	7·04	20·15	11·30	14·86
Nine	29·29	8·88	23·05	14·03	18·81
Twelve	28·93	8·63	24·31	12·53	18·10

The maximum yield was obtained with nine ploughings. Nine ploughings gave 3·95 and 6·89 md. additional yield over six and three ploughings respectively. Khan and Majumdar (1958) further reported that the proportion of both the mother aggregates as well as the water-stable aggregates was found to be maximum in plots receiving nine ploughings. Further, it was observed that increasingly more moisture was conserved as the number of cultivations were increased from three to nine. Over-cultivation (12 ploughings) had a slightly adverse effect on the yield of the wheat crop.

Time of sowing. The time of sowing has a marked influence on the yield of wheat crop. Other agronomic practices like spacing and seed rate may also vary with the time of sowing. Time of sowing varies widely over the wheat-growing area. For example, major area under wheat is sown during October in Assam, Bihar, Bombay, Orissa, W. Bengal and Rajasthan, while in the Punjab, Delhi, Himachal Pradesh and parts of Madhya Pradesh it is sown during November. Field experiments have been conducted in different parts of India to work out the optimum time of sowing. In Saurashtra (Gujarat State), trials were conducted at Halvad and Junagadh. The results obtained from 1954–55 to 1956–57 at the Agricultural Research Farm, Halvad, are given in Table LI.

The early November sowings gave higher yields than the late November sowings (Motwani, 1958). From 1952–53 to 1956–57, trials were conducted at the Central Experimental Station, Sagdivid, Junagadh, Gujarat (Table LII).

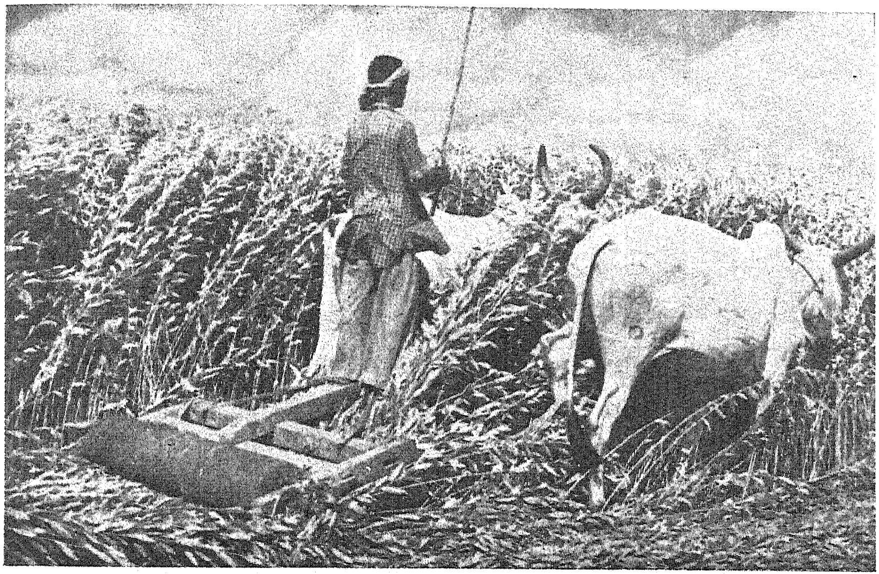

PLATE 76. Levelling of green-manure crop of sunnhemp preparatory to burying in

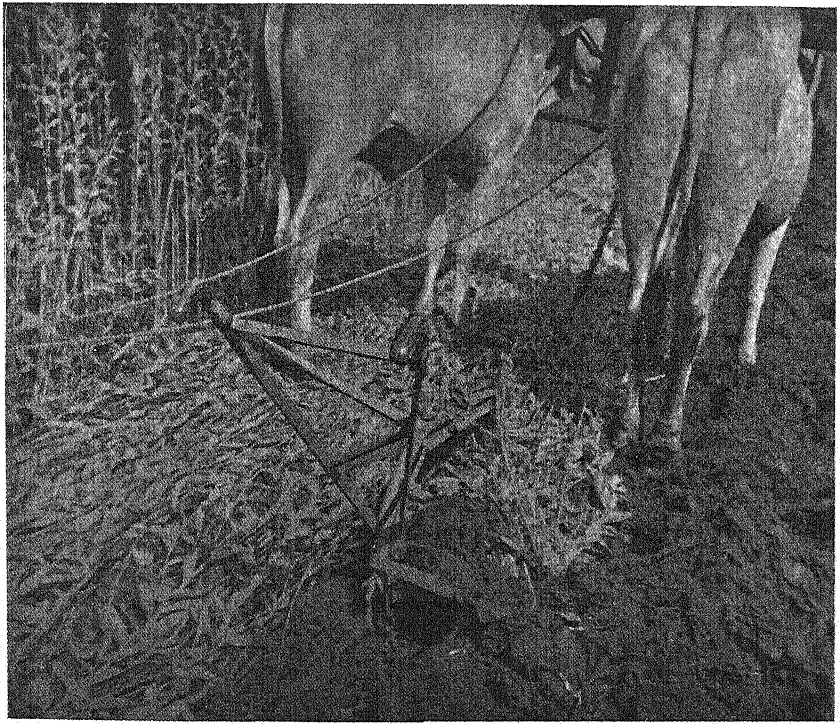

PLATE 77. Burying in of the green-manure crop

PLATE 78. Discing before cultivation

PLATE 79. Preparatory tillage with tractor

TABLE LI. YIELD OF WHEAT GRAIN IN MD. PER ACRE WHEN SOWN ON DIFFERENT DATES

Year	Sowing dates		
	2nd Nov. to 6th Nov.	11th Nov. to 16th Nov.	20th Nov. to 26th Nov.
1954–55	4·17	4·37	4·66
1955–56	22·91	22·53	17·91
1956–57	19·04	19·52	19·72
Mean	15·37	15·47	13·76

TABLE LII. EFFECT OF DIFFERENT DATES OF SOWING ON WHEAT YIELD (MD./ACRE)

Years of experimentation	Wheat variety used	Sowing dates						
		10th Oct.	20th Oct.	30th Oct.	9th Nov.	19th Nov.	29th Nov.	9th Dec.
1952–53	N.P. 165	17·01	21·02	22·23	20·25	—	—	—
1953–54	N.P. 718	24·30	30·15	32·74	28·74	25·50	—	—
1955–56	Kenphad	12·39	18·61	26·24	29·76	—	—	—
1956–57	Kenphad	—	10·81	17·76	17·72	16·80	9·02	7·63
Average		17·94	20·15	24·75	24·13	21·17	9·02	7·63

Irrespective of the variations in weather from year to year, the optimum period for sowing wheat in Junagadh area appears to be from last week of October to first week of November (Jadeja and Lakhani, 1957).

In the Deccan tract of Bombay State an experiment was conducted at the Agricultural Research Station, Niphad, Nasik district. The results of this experiment are summarized in Table LIII.

TABLE LIII. GRAIN YIELD OF WHEAT IN MD. PER ACRE IN THE 'SOWING-CUM-SPACING' EXPERIMENT UNDER RAINFED CONDITIONS AT NIPHAD

Year	Sowing dates and spacings									
	24th Sept		1st Oct.		8th Oct.		15th Oct.		22nd Oct.	
	10″	13″	10″	13″	10″	13″	10″	13″	10″	13″
1948–49	2·43	2·28	3·47	3·41	3·46	3·31	3·91	3·65	3·74	3·66
1949–50	2·49	2·43	2·81	2·97	2·74	2·18	3·83	3·59	3·28	3·03
1950–51	—	—	3·34	3·20	3·81	3·76	4·16	4·49	4·59	4·05
Average	2·46	2·35	3·20	3·19	3·34	3·08	3·97	3·91	3·87	3·58

The sowing of wheat on 15th October under unirrigated condition gave the maximum grain yield and the next suitable date was October 22.

Experiments undertaken at the Government Experiment Farm, Powerkheda (M.P.), on deep black soils indicated that early sowing in October leads to considerable mortality of the seedlings. Sowings done in the third week of October gave the best stand of the crop (Kalamkar and Ekbote, 1954). For the Agra Division of Uttar Pradesh, Gupta (1956) found October 22 to November 5 to be the optimum period for sowing wheat. Similarly, for other parts of Uttar Pradesh, the latter half of October has been found to be the optimum time from a large number of experiments conducted over several years (Mitra and Mathur, 1949).

At the Indian Agricultural Research Institute, New Delhi, October 25 has been found to be the optimum time for sowing wheat under irrigated conditions. Wheat yields obtained were 26·2, 24·2 and 21·7 md. per acre for the October 25, November 12 and December 1 sowings respectively (Raheja, 1959). It was further observed that the disadvantage due to early or late sowings could be compensated to a certain degree by additional application of 20 lb. of nitrogen per acre (Chandnani, 1954).

Seed rate. There is considerable variation in seed rate used in different parts of India. A large number of experiments have been conducted in various states to work out the optimum seed rate under irrigated and rainfed conditions. Theoretically, a good crop of wheat has about 60,000 plants to an acre. As such, about the same number of seeds weighing about 6 lb. only should suffice, provided each seed is properly spaced and successfully germinates and each plant survives till harvest. Under field conditions, however, quite a high rate of mortality occurs depending on the soil, weather conditions and insect and fungal damage. A much higher seed rate is, therefore, required to secure an optimum and effective plant population for normal yield.

TABLE LIV. EFFECT OF SEED RATE ON YIELD OF GRAIN AND STRAW OF WHEAT (MD./ACRE)

Year of experimentation		Normal seed rate*		Heavy seed rate**	
		Grain yield	Straw yield	Grain yield	Straw yield
1936	Rainfed	3·66	8·51	6·26	11·82
	Irrigated	7·82	15·10	6·26	18·25
1942	Rainfed	16·85	37·73	22·30	53·14
1943	Rainfed	9·41	17·43	11·31	21·02
	Irrigated	20·25	32·62	26·69	50·13
1944	Rainfed	17·53	57·21	21·90	76·53
1945	Irrigated	22·13	110·83	24·73	135·52
Average	Rainfed (for four seasons)	11·86	30·22	15·44	40·63
	Irrigated (for three seasons)	16·73	52·85	19·23	67·97

*60–80 lb./acre. **90–110 lb./acre.

The experiments conducted in Uttar Pradesh with seed rates varying from 40 to 120 lb. per acre indicated that under average soil conditions the optimum seed rate was 80 lb. per acre. When the soil is heavy and moist or the field is deficient in soil

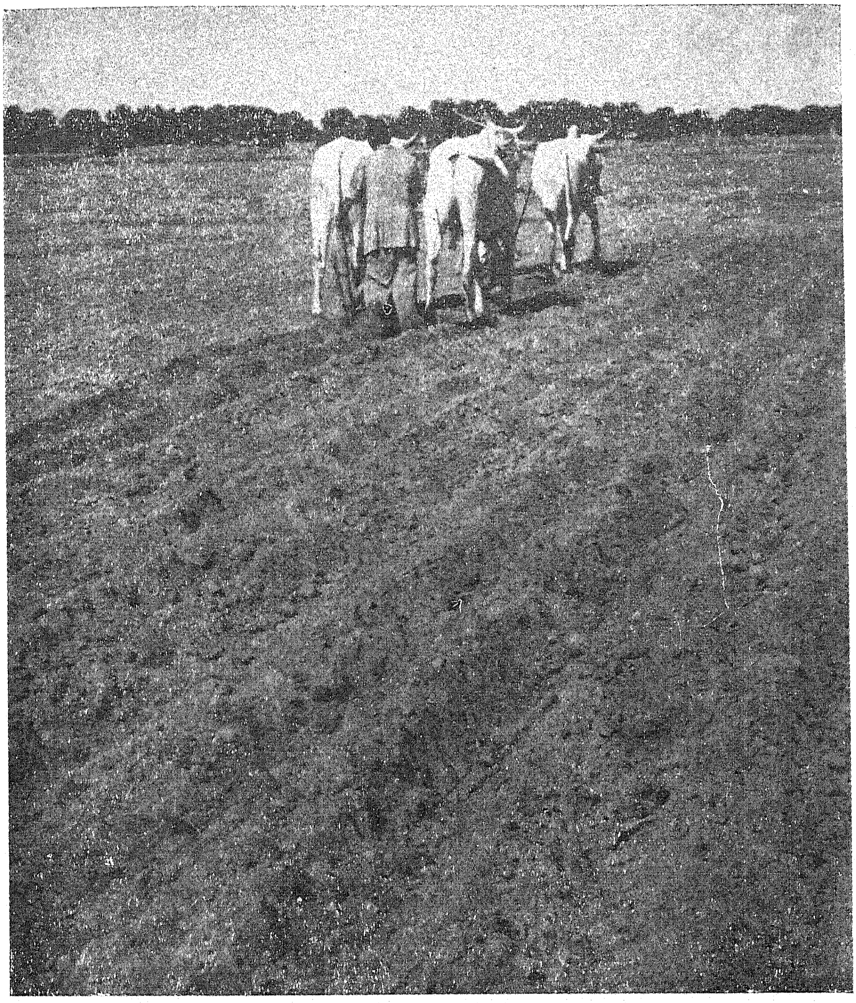

PLATE 80. Final cultivation with *desi* plough

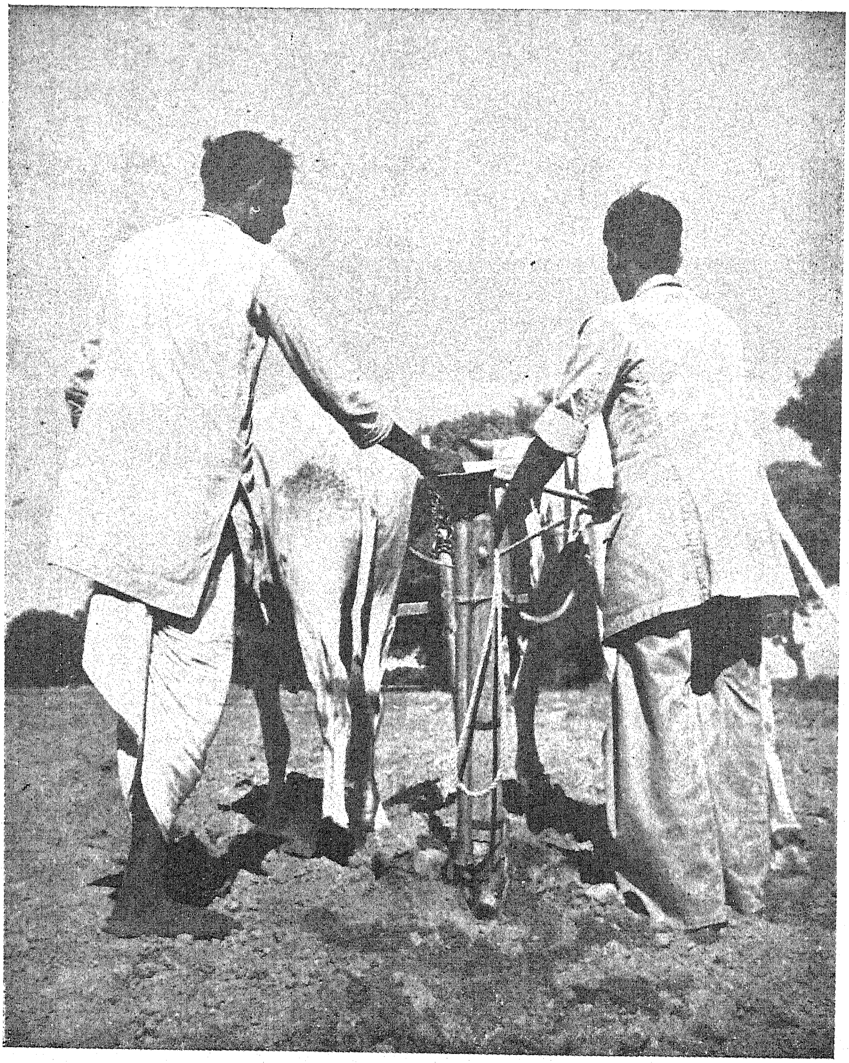

PLATE 81. Dropping seed by local drill

moisture, higher seed rate is required (Mitra and Mathur, 1949). To study the effect of a heavier seed rate under dry and irrigated conditions, Chinoy (1947) conducted a series of experiments with a number of varieties from 1936 to 1945 (Table LIV).

Under rainfed as well as irrigated conditions heavy seed rate gave increased yields over normal seed rate.

In Bombay State experiments have been conducted at Niphad, under both rainfed and irrigated conditions, to determine the optimum seed rate (Table LV).

TABLE LV. EFFECT OF DIFFERENT SEED RATES ON THE YIELD OF WHEAT GRAIN UNDER RAINFED AND IRRIGATED CONDITIONS (MD./ACRE)

Year of experimentation	Seed rate (lb./acre)				
	40	50	60	70	80
	Irrigated				
1944–45	10·10	9·89	9·42	9·76	9·79
1945–46	10·32	10·40	10·78	9·92	9·33
1947–48	9·01	8·69	8·74	8·56	8·08
1948–49	18·80	17·65	17·70	17·03	16·60
Average	12·05	11·65	11·77	11·39	10·92
	Rainfed				
	Seed rate (lb./acre)				
	40	45	50	55	60
1944–45	7·15	6·78	7·05	7·46	7·27
1945–46	7·09	6·62	6·93	6·18	6·42
1947–48	8·90	8·55	9·08	9·17	9·67
Average	7·71	7·31	7·69	7·60	7·78

Under irrigated and rainfed conditions, 40 lb. seed per acre was found to be optimum in the medium black soil of Nasik district (Solomon and Patil, 1958; Solomon and Shendge, 1957; Chavan and Patil, 1956). At Powerkheda (Madhya Pradesh) 80 lb. per acre was found to be the optimum seed rate for rainfed condition as against 100 lb. per acre commonly used by the cultivators (Kalamkar and Ekbote, 1954).

At the Indian Agricultural Research Institute, New Delhi, a factorial experiment was conducted for three years to study the interrelationship of seed rates, doses of nitrogen and delta of irrigation. During none of the three years were the interactions with nitrogen doses or delta of irrigation found to be significant (for results relating to seed rates *see* Table LVI).

TABLE LVI. EFFECT OF SEED RATES ON GRAIN YIELD OF WHEAT (MD./ACRE)

Year of experimentation	Seed rate (lb./acre)		
	40	60	80
1955–56	23·2	22·6	23·8
1956–57	18·5	18·6	17·1
1957–58	36·3	35·5	35·6
Average	26·0	25·6	25·5

In none of the three years the differences in grain yield due to seed rates of 40, 60 and 80 lb. per acre were significant. On the whole a seed rate of 40 lb. per acre appeared to be the optimum (Raheja, 1959). In another experiment with two wheat varieties, three dates of sowing, three spacings between rows and three seed rates, the seed rate of 50 lb. per acre gave slightly higher yield than the seed rates of 70 and 90 lb. per acre.

Spacing. The stand which a soil can adequately support for optimum production is generally dependent upon the fertility status and moisture level of the field. Moreover, an early and poorly tillering variety has to be planted closer than a late and profusely tillering variety. Likewise, the late-sown wheat has to be planted closer to compensate for the lesser number of tillers and a shorter growth period. On a fertile soil, comparatively smaller plant population may be required for optimum yields due to favourable conditions for profuse tillering and healthy growth.

In Bombay State, results of experiments at various stations indicate that seed should be drilled 9 to 12 inches apart with two or three coulter drill (Solomon and Shendge, 1957). The results obtained at Niphad are given in Table LVII.

TABLE LVII. GRAIN YIELDS IN MD. PER ACRE OBTAINED WITH 10″ AND 13″ SPACINGS AT NIPHAD UNDER RAINFED CONDITIONS

Year of experimentation	Spacing between lines	
	10 inches	13 inches
1948–49	3·40	3·26
1949–50	3·03	2·84
1950–51	3·98	3·88
Average	3·47	3·33

Under rainfed conditions, ten-inch spacing proved to be optimum (Chavan and Patil, 1956). On deep black soils of Narmada Valley the appropriate distance between rows has been found to be 12 inches for rainfed wheat and nine inches for irrigated wheat when sown with country plough (Kalamkar and Ekbote, 1954). In Uttar Pradesh, results of experiments conducted at various stations indicate that nine-inch spacing between rows is optimum (Mitra and Mathur, 1949). Similar results have been obtained at the Indian Agricultural Research Institute, New Delhi, where experiments have been conducted from 1955 to 1957 (Raheja, 1959).

Methods of sowing. Usually wheat is sown in lines with country plough or with a *nari* plough in the Punjab, Delhi, Uttar Pradesh and Madhya Pradesh. In Saurashtra under irrigated conditions, wheat is drilled in rows 18 inches apart, but the operation is repeated thrice in different directions on the same plot so as to cover it thickly with seed. On germination, the field gives the appearance having been sown by broadcast method. This local method in Saurashtra was compared with drilling in one direction with rows nine inches apart. The results of these trials as reported by Motwani (1958) are given in Table LVIII.

TABLE LVIII. WHEAT YIELD AS AFFECTED BY DIFFERENT METHODS OF SOWING

Year	Place	Wheat yield in md./acre	
		Local method	Line sowing (9″ inter-row space)
1952–53	Junagadh	12·57	15·47
1955–56	Halvad	21·64	24·74
1956–57	Halvad	17·52	19·29
1956–57	Karsangadh	15·84	19·50
1956–57	Fulgram	14·02	16·92
	Average	16·32	19·18

At all the places, line sowing gave better results than local method of sowing. It was further observed that line sowing enabled a reduction in seed rate from 100 to 80 lb. per acre.

Among the different sowing implements compared at Hoshangabad (M.P.) five-tyned McCormick seed drill has proved as efficient for sowing wheat as local seed drills, such as *nari*, *dufan* and *tifan*. However, sowing with five-tyned seed drill was more economical than with the local seed-sowing drills (Kalamkar and Ekbote, 1954).

Seed quality. Usually seeds of good quality free of weed seeds are used for sowing purposes. Experiments conducted by Ekbote and Sahasrabudhe (1948), Mitra and Mathur (1949), and Ekbote and Dhannalal (1950) have brought out the fact that the rust-affected, shrivelled grain of wheat is also suitable for seed purposes. In these experiments, badly shrivelled seeds gave yields of over 20 md. per acre when all other conditions were favourable.

Intercultivation. Intercultivation is mainly given to eradicate weeds. This aspect has been elaborated separately in the section on weed control.

Earthing up. Lodging is common in wheat crops receiving heavy doses of nitrogenous fertilizers. Earthing up of wheat crop in the first week of January or just before the soil starts cracking has been found to increase the yield appreciably in Hyderabad (Yardi, 1955). Earthing up in wheat before first irrigation reduced lodging and increased the efficiency of water use in experiments conducted at the I.A.R.I.

Harvesting and threshing. When the straw turns yellow and becomes fairly dry, wheat is harvested. In many areas, farmers tend to keep the crop standing in the field till it is dead ripe. This may result in the loss of grains through shedding and breakage of tillers. Harvesting is done mostly by hand with saw-toothed sickles, though in some areas a sickle without serrations is also used. Like sowing time, the harvesting time also varies widely from region to region over the wheat-growing area. While harvesting starts as early as last week of January in Deccan, it may extend up to July in Himachal Pradesh. The normal wheat-harvesting periods for the different states are given below.

Deccan and southern parts of Bombay State.	January–February
Madhya Pradesh, parts of Gujarat, and Bombay	February–March
Northern parts of M. P., West Bengal, Bihar, Orissa, U. P. and Delhi	March–April
Punjab and Himachal Pradesh	April–May

Immediately after harvest the sheaves are removed to specially prepared threshing floors where they may either be stacked for some time or threshed immediately. The most common method of threshing is by making bullocks tread over the sheaves spread over the threshing floor. Normally two pairs of bullocks handled by two men can thresh about 20–30 md. of wheat in three days. Apparently this is a very slow and laborious method. Many cultivators use what they call the *palla* system of threshing. In this method, a weighted wooden frame or beam known as *palla* is yoked to the bullocks and is dragged behind the bullocks treading round and round. About 20–25 md. wheat grain can be threshed in a day by this method. However, a very simple and useful implement for threshing wheat is the bullock-drawn Olpad thresher. It can thresh 30–40 md. wheat grain per day with a pair of bullocks. Recently, on larger farms tractor-drawn, off-set and tandom-disc harrows have been used with advantage for threshing wheat. With a 12-feet disc harrow, about 150–200 md. of wheat grain can be threshed in two days time. On still larger farms, like the State Mechanized Farms, stationary thresher and even combine harvesters and threshers have been used.

For winnowing, the cultivators depend on wind and as such this operation is rather slow and to a certain extent uncontrollable. Manually driven Hoshangabad winnower has been of some use, but more recently fan devices worked by manual, mechanical or electric power have proved quite useful to expedite the winnowing process.

WHEAT IN ROTATION

It is not desirable or profitable to grow wheat continuously on the same land year after year. The results of the long-time experiments at the Rothamsted Experimental Station in England are quoted below to illustrate this point and to indicate the trend in yield when wheat is grown in rotation or in continuous culture.

YIELD OF WHEAT AT ROTHAMSTED FARM 1851–1919

Treatment	Average yield in bushels per acre
Continuous wheat, unfertilized	12·33
Continuous wheat, fertilized	23·58
Wheat in a 4-year rotation without fertilizer (Turnip-barley-clover-wheat)	24·05
Wheat in 4-year rotation, fertilized	32·49

It is obvious that the yield of wheat in rotation was almost double the yield of continuous wheat, both unfertilized. Even under conditions of fertilizer application wheat in rotation yielded about 40 per cent more than continuous wheat culture.

The crops that are used in rotation with wheat are determined by the climate, length of growing season, soil type, fertility and the kind of farming. As wheat crop takes about 100 to 160 days to mature over the principal wheat-growing areas in India,

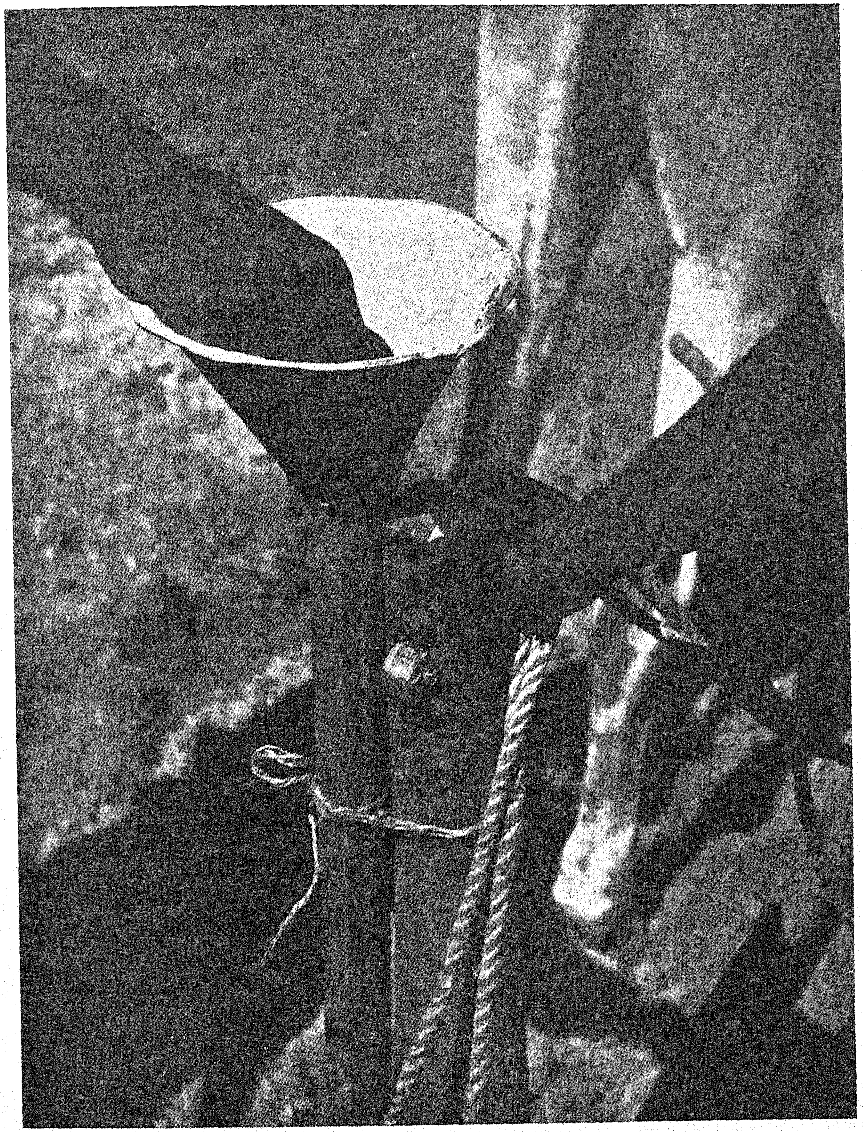

Plate 82. Closer view of dropping seed by local drill

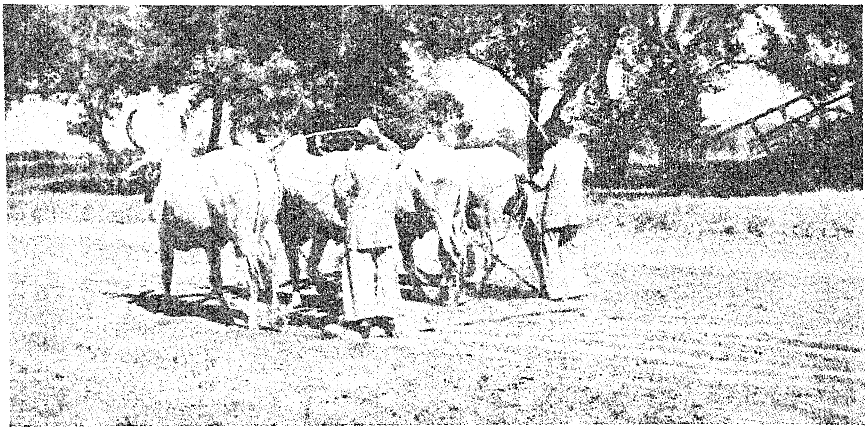

PLATE 83. Planking the seed-bed after sowing

PLATE 84. Bullock-drawn seed drill in operation

it is possible to take a crop in the preceding *kharif* season in rotation with wheat if the soil moisture is not a limiting factor and enough time is allowed for the preparation of the seed-bed in between the preceding *kharif* and the sowing of wheat in the following *rabi.* Thus, under unirrigated conditions wheat is grown, either after fallow or after a short-duration (60–80 days) legume, which allows conservation of soil moisture received through natural precipitation during the month of September. As different crops, such as gram, maize, *jowar*, *bajra*, cotton, sugarcane and berseem can be grown in rotation with wheat under irrigated conditions, rotations with varying cropping intensities are possible. In North India, wheat is rotated with cotton, sugarcane and *toria* (*Brassica campestris*) under irrigated conditions. In Madhya Pradesh and peninsular India groundnut, sesamum, linseed and gram are the principal crops grown in rotation with wheat. Around cities wheat is rotated with vegetable crops also. With increased facilities for irrigation and appreciation of fertilizer use wheat is rotated in some areas with crops like maize, paddy and jute.

Studies on the effect of the various crop sequences on the yield of wheat have been reported only from a few research centres. To study the comparative effect of different crop rotations an experiment was laid out in 1951 at the Indian Agricultural Research Institute, New Delhi. Eight rotations, each including wheat as one of the crops, were compared. The crop sequences were so arranged that wheat crop occurred after fallow in four rotations, after green manure in two rotations, and after maize and cowpea in three rotations. The results of various crop rotations on wheat yield as summarized by Chandnani *et al.* (1960) are presented in Table LIX.

TABLE LIX. EFFECT OF DIFFERENT CROP ROTATIONS ON YIELD IN MD. PER ACRE OF WHEAT GRAIN

Rotations	1951–52	1952–53	1953–54	1954–55	1955–56
Maize-wheat-fallow-wheat-cowpea	7·5	19·3	20·3	23·5	21·0
Cotton-berseem-fallow-wheat	7·1	27·0	25·9	33·0	24·0
Maize-wheat-cotton-berseem-cowpea	5·6	23·0	24·6	27·3	23·7
Gr. manure-wheat-maize-pea	6·9	27·3	23·9	25·8	22·1
Fallow-wheat-fallow-pea-cotton-fallow	8·3	27·2	26·4	30·4	23·4
Fallow-wheat-cotton-fallow-cane-cane	7·6	23·0	25·6	27·0	25·0
Maize-wheat-fallow-pea-maize-berseem	6·3	26·1	24·3	29·3	20·7
Gr. manure-wheat-fallow-potato-cane-cane	7·5	27·1	25·1	28·6	23·8
F test	Not sig.	Sig.	Sig.	Sig.	Sig.
S. E.m.		± 1·98	± 1·06	± 1·89	± 1·22
C.D. at 5 %	—	5·78	3·11	4·16	2·94

The results given in the Table above indicate that, in general, the yield of wheat after maize and cowpea was lower than that of wheat after fallow or green manure. It was further observed that the introduction of berseem in the rotation with maize and cowpea reduced the ill effect of maize and cowpea. Wheat yields were favoured by including either a fallow or a green manure or a berseem crop prior to wheat in crop sequence.

Experiments conducted at Sabour (Bihar) with two *kharif* legumes, viz., soybean (*Glycine max*) and *kalai* (*Phaseolus mungo*) showed that the yields of wheat after soybean were decreased by about 75 per cent, but increased by about 110 per cent after *kalai*, as compared to the yield of wheat obtained after maize. Experiments conducted in Uttar Pradesh indicated that wheat grown after *mung* (*Phaseolus radiatus*, Type-1) gave better yield than wheat grown after sunnhemp, cowpea, groundnut and *urid* (*Phaseolus mungo*).

Experiments carried out at Rohtak (Punjab), having an average annual rainfall of 20 inches, indicated that for best results wheat should be rotated with *guar* in the following sequences:

(1) Wheat-*guar*-fallow-fallow (two years)
(2) Wheat-fallow-fallow-*guar*-fallow-fallow (three years)

MIXED CROPPING WITH WHEAT

The system of mixed cropping is widely practised in India and has been an important feature of Indian agriculture. Mixed cropping in relation to various field crops has been studied in great detail by Aiyer (1949). According to him, the extent of mixed cropping varies from locality to locality and from crop to crop. The results of survey conducted by him (1949) indicated that in the Jullundur circle of the Punjab, mixed cropping amounted to 15 per cent in cotton, 20 per cent in *jowar*, 20 per cent in maize, 10 per cent in *bajra*, 40 per cent in barley, 60 per cent in wheat and 80 per cent in gram. While working out the extent of mixed cropping in wheat in Madhya Pradesh, Kalamkar (1949) recorded that the practice of growing wheat alone or in mixture with gram (known as *birra*) differed widely from tract to tract (Table LX).

TABLE LX. AREA UNDER PURE WHEAT AND *BIRRA* IN DIFFERENT TRACTS OF MADHYA PRADESH

(Average of 10 years ending 1939–40)

Tract	District	Pure wheat (acres)	*Birra* (acres)	*Birra* (as per cent of pure wheat)
Open	Saugor	4,02,271	72,021	17·9
	Hoshangabad	3,70,396	38,235	10·3
Haveli	Jabbalpur	1,10,565	1,98,136	169·6
	Narsingpur	82,700	1,53,890	176·9

The practice of mixed cropping with wheat is more common in the area practising *haveli* system than in the areas where open system is practised.

According to Aiyer (1949), 12 crops are usually sown mixed with wheat. These crops are barley, *jowar*, coarse rice (*sathri*), *ragi*, gram, wild pea, mustard, rape, *sarson*, turnip, safflower and linseed. Among the mixed crops listed, barley is the most important among cereals and the others are of very minor importance. Likewise

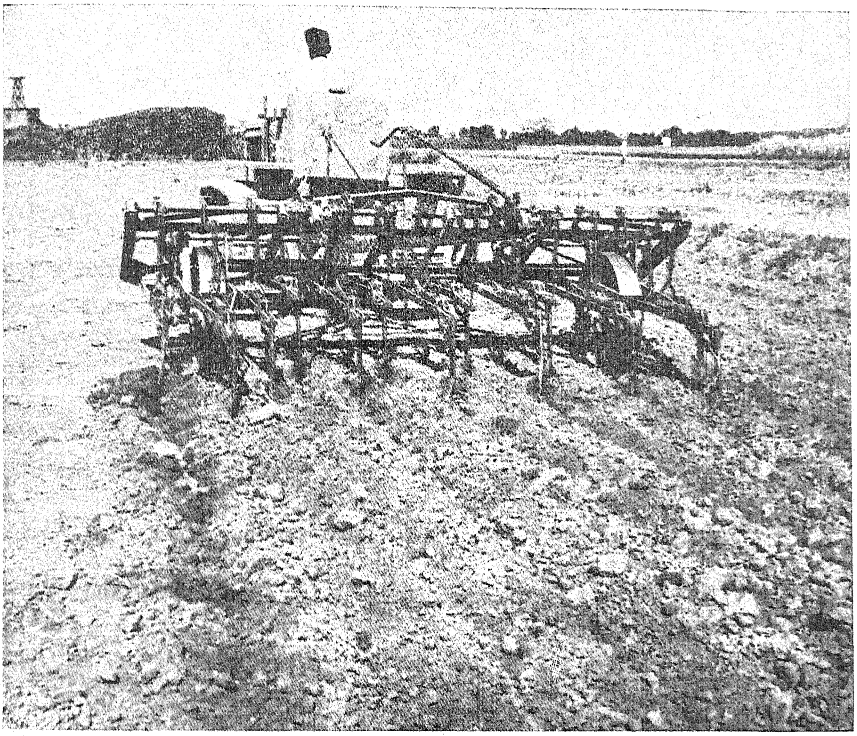

PLATE 85. Sowing with tractor-drawn seed drill

PLATE 86. Harvesting wheat (according to the traditional method) with sickles

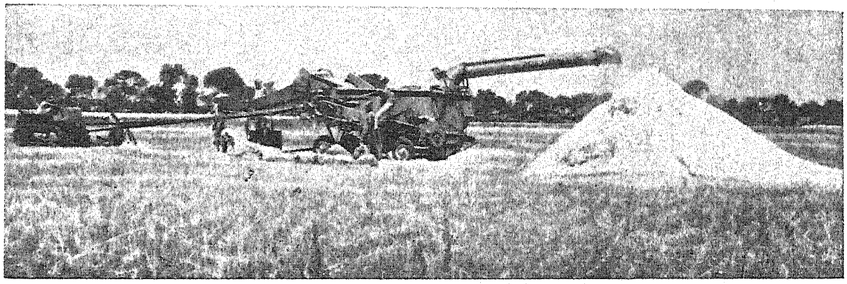

PLATE 87. Mechanized harvesting of wheat

among the pulses, gram is not only the commonest and the most important but is almost the only pulse crop mixed with wheat. Among the other crops linseed is the most important with safflower as a very minor crop, except in parts of Maharashtra and Andhra Pradesh. The mustards are very commonly grown mixed with wheat throughout northern India, mostly in rows alternating with 8–12 rows of wheat. The mixed crop may consist of one, two or more crops other than wheat.

The proportions of the components by weight of seeds in the mixed cropping of wheat vary widely. The following are the proportions in respect of some of the most popular mixtures:

Crop in mixture	*Range of proportion*
1. Barley	1: 1 to 6: 1
2. Gram	1: 1 to 10: 1
3. Linseed	9: 1 to 15: 1
4. Mustard (row crop)	1: 1 to 50: 1

Though the system of mixed cropping has been widely practised by cultivators, not much investigation has been done on this aspect. The profitability of mixed cropping from the point of crop production has been studied only by few research workers. At Pusa (Bihar), Howard (*fide* Aiyer, 1949) observed that there was a marked advantage in growing mixed crops of gram and wheat on soils where nitrogen was the limiting factor, while in Uttar Pradesh the local practice of growing wheat and gram mixed was less profitable than sowing wheat and gram in rotation. In experiments comparing the yields from wheat-gram mixture with those from wheat and gram grown pure, conducted at Nagpur Farm, wheat yield was 895 lb. per acre in the pure crop and the gram yield was 453 lb. as against 553 lb. of wheat and 145 lb. of gram in the mixed crop (all averages over a period of 16 years). Thus, mixed cropping was found to be unprofitable (Allen, 1933; *fide* Aiyer, 1949). In another experiment conducted at Nagpur for ten years, the average yield of the pure crop of wheat was 348 lb. per acre while that from the mixture (two-thirds wheat and one-third gram) was 244 lb. of wheat and 119 lb. of gram. As this mixture gave low yield of gram, it was slightly less economic, compared to the wheat crop grown in pure form.

The profitability of mixed cropping has been worked out at the Indian Agricultural Research Institute, New Delhi. When wheat and gram crops were grown separately as well as in association during 1948–49, it was observed that association resulted in a very great suppression of gram and yield of gram component of the mixture was almost negligible (Dakshindas, 1949). It was further observed that the mixed yield of wheat and gram was a little less than of wheat grown alone. In another experiment conducted during 1949–50 the associated growth of wheat-pea showed deleterious effects on both components, causing a reduction in number of tillers and branches, green weight and dry weight produced, with the result that the yield of grain was reduced by 22 per cent in the case of wheat and 36 per cent in pea, compared to yields obtained when these crops were grown pure (Dhaka, 1950).

Mirchandani and Misra (1957) reported that the best ratio for wheat to pea or lentil is 1:1 under Delhi conditions.

MOISTURE REQUIREMENTS OF WHEAT

Next to temperature, the availability of moisture influences the distribution of wheat with respect to area and production in the world. As rainfall is the natural source of moisture supply to plants, wheat cultivation is largely restricted to areas receiving 15 to 45 inches rain annually. The optimum precipitation for wheat is considered to be about 32 inches per annum. Very little wheat is grown in areas receiving less than nine inches rain (Royen, 1954). It is, however, not the total rainfall but its distribution which is important. In many wheat-growing countries in the West, the seasonal rainfall is adequate and well distributed to meet the water needs of this crop. However, in the wheat-growing areas of India (Table LXI) the weather from October to February during the crop season is relatively dry, except for occasional showers in some parts. The period during June to September generally receives heavy monsoon rains which mainly contribute to the storage of soil moisture which is available to wheat in the succeeding *rabi* season.

TABLE LXI. RAINFALL IN INCHES IN WHEAT-GROWING AREAS IN INDIA (Data of Ramdas, 1946)

State	Dec. to Feb.	March to May	June to Sept.	October to Nov.	Total
U. P., E. & W.	1·90	1·24	33·71	1·50	38·35
M. P., W.	1·47	1·14	41·04	1·76	45·41
Punjab, E. & N.	2·76	1·89	18·23	0·37	23·25
Bombay	0·51	2·13	24·41	3·82	30·87
Rajputana (Rajasthan) W.	0·62	0·56	11·74	0·12	13·04
—do— E.	0·96	0·78	22·91	0·55	25·20
Bihar	1·41	3·30	40·96	2·54	48·21

Interrelation of soil type, rainfall and distribution of wheat in India. As the texture and the depth of soil greatly influence its moisture-storage capacity, these, apart from rainfall, play an important part in the distribution of unirrigated wheat (Table LXII).

The medium black soils of Madhya Pradesh, Bombay and the neighbouring areas of Rajasthan have high moisture-storage capacity as indicated by their field capacity which is about 40 per cent. The light sandy or sandy loam alluvial soils of the Punjab, U.P. and the border areas of Rajasthan and Bihar have low field capacity (13–16 per cent). However, the redeeming feature of the latter soils is their depth and low wilting point (6–9 per cent), as compared to the high wilting point (about 20 per cent) of the black soils.

It appears that high moisture reserves built up during monsoon rains on the heavy black cotton soils account for the large acreage under unirrigated wheat in Madhya Pradesh, parts of Bombay and the neighbouring areas of Rajasthan, in spite

TABLE LXII. DISTRIBUTION OF AREA UNDER WHEAT IN 1955–56 IN RELATION TO SOIL TYPE

State	Total area ('000 acres)	Unirrigated area (percentage)	Soil type
U.P.	9,875	53·7	Alluvial of Indo-Gangetic origin (some impregnated with salts)
M.P.	5,976	98·1	Medium black
Punjab	4,609	60·6	As in U. P.
Bombay	3,217	83·7	Medium black
Rajasthan	2,310	44·0	Mixed
Bihar	1,444	84·8	Gangetic alluvium, calcareous and alluvial soil
Other states	1,794	—	—

of the fact that only a small amount of rain is received during the period from December to February. The expectation of winter rains in the Punjab and the western parts of U.P. is probably responsible for considerable acreage under unirrigated wheat (usually sown mixed with gram) even though stored moisture is generally inadequate, as the soils are of light and medium texture and rains recede early. On wet (*sailaba*) lands near rivers and in low-lying lands, where water accumulates, wheat cultivation is often feasible without irrigation. Thus, the topography of land is also an important factor for the cultivation of unirrigated wheat. Certain areas in the Gangetic alluvium, as in north Bihar, are highly retentive of moisture and these too are utilized for wheat cultivation without irrigation.

Soil moisture in relation to plant development. Adequate soil moisture is required for the normal development of the wheat plant at all stages of growth, viz., germination, tillering, jointing, heading, grain development and maturation. The optimum moisture requirement may, however, vary with the stage of growth.

For germination and quick emergence of seedlings, the soil moisture should be well above the wilting percentage, i.e., 50–70 per cent of field capacity.

Tillering is influenced directly by moisture supply. The *barani* (unirrigated) wheat invariably presents a thin appearance as it produces few tillers. Heavy tillering is a function of adequate moisture supply obtaining under irrigated conditions or under conditions of adequate rainfall. The data in Tables LXIII and LXIV illustrate the relationship between tillering and soil moisture.

TABLE LXIII. TILLERING AS INFLUENCED BY MOISTURE AND NUTRIENT STATUS OF SOIL (Data of Mann, 1956)

Field studies	Average tillers per plant					
	Check	N	P	K	NP	NPK
1953 (dry year)	5·5	5·3	6·3	5·6	6·6	6·6
1954 (moist year)	8·5	10·6	12·6	9·5	14·2	16·4

TABLE LXIV. NUMBER OF TILLERS PER PLANT UNDER DRY AND IRRIGATED CONDITIONS
(Data of Azzi, 1956)

Stations	Dry	Irrigated
Algiers	6·25	7·88
Rabat	3·92	4·63

The relationship between tillering and moisture supply can be explained in terms of the physiology of tiller production. In wheat, the first node or the crown is formed very near the soil surface irrespective of the depth of sowing. Coronary roots start developing at this node and at the successive underground nodes which are closely spaced. The lateral buds at these nodes give rise to tillers. The adventitious roots, which help in the establishment of tillers, can form only in moist soil. Tillering is, therefore, related to the moisture in the surface layer of the soil.

The jointing stage represents the meristematic activity (cell-division) phase. Under natural conditions, the moisture supply is rarely so low as to limit node production.

The heading stage, when the internodes elongate as a result of the enlargement of cells, is the critical period when the plants suffer most from soil-moisture deficiency (Tulaikov, 1926; Moliboga, 1927; Azzi, 1956).

The grain number per ear and the grain size are reduced to a considerable extent by drought (Asana *et al.*, 1958; Thakar, 1959).

During the maturation phase, the plants lose moisture rapidly and the yield is usually not affected by changes in soil moisture at this stage. It may, however, be mentioned that plentiful moisture supply during grain development and maturation may reduce gluten and protein contents and thus affect the quality of wheat. The best wheats are usually produced in regions which have dry conditions during the maturation phase.

March of transpiration. The actual consumption of water by wheat at different stages of growth depends not only on the critical moisture requirement for each stage but also on the size of the plant and the external conditions. The march of transpiration was studied at Pusa by Leather (1911) and at Rohtak by Rao (1951). The transpiration curves show that, apart from local variations influenced by weather conditions, there was a slow and steady rise in the rate of transpiration up to the middle of January. Thereafter, the rate rose rapidly to peak values towards the middle of March, followed by a steep fall. Thus, the transpiration rate in wheat was low during germination and tillering, high during the heading stage, attained maximum value during the period of grain development and fell off during the maturation phase. Transpiration followed more or less the same trend as the absolute growth rate. The rising temperatures during February–March also contributed to the steep rise of transpiration during the grain-formation period. The relative transpiration losses during the different stages of growth of wheat are presented in Table LXV.

The transpiration losses per week were maximum during the earing stage.

Studies on the rate of water use (as evapo-transpiration) at the I.A.R.I. in the plots receiving four irrigations have also shown progressively increasing water use till the middle of March, followed by a decrease (Table LXVI).

TABLE LXV. PERCENTAGE TRANSPIRATION LOSSES DURING DIFFERENT STAGES OF GROWTH (Data of Rao, 1951)

Stage	Percentage transpiration	Period (weeks after sowing)
Tillering	2	3–6
Stem elongation	30	7–14
Earing	35	15–18
Maturity	33	19–23

The peak rate of water use was recorded during the period of grain development.

Water requirements. Information on this aspect is only available from pot culture and soil moisture studies and from irrigation experiments. From pot culture studies at Pusa, Leather (1910) found the transpiration ratio of wheat to be 850 under unmanured and 550 under manured conditions. Based on these values, he calculated the absolute water requirements for varying yields of dry matter (Table LXVI).

TABLE LXVI. RATE OF WATER USE IN WHEAT (Data of Pandey and Singh, 1958)

Period		Water use (inches/day)
29/10 to 28/12	..	0·065
31/12 to 4/2	..	0·076
7/2 to 21/2	..	0·092
23/2 to 14/3	..	0·197
16/3 to 3/4	..	0·093

The figures in Table LXVII indicate that 11–12 acre-inches of water were transpired by wheat crop to produce 4,000 to 5,000 lb. dry matter. At Banaras, however, Singh *et al.* (1935) estimated a lower value of 8·56 inches as the total water requirement of wheat producing 4,079 lb. total dry matter per acre. The computed water requirements included 1·1 in. water which evaporated from bare pots. The difference in the two estimates of water requirements was due to lower transpiration ratio (408) recorded at Banaras.

TABLE LXVII. ABSOLUTE WATER REQUIREMENTS OF WHEAT (Data of Leather, 1910)

Dry weight (lb./acre)	1,000	2,000	3,000	4,000	5,000
Transpiration ratio	850	775	700	625	550
Absolute water requirement (acre-in.)	3·7	6·8	9·3	11·0	12·1

Soil moisture studies carried out by Leather (1911) in unirrigated wheat under field conditions (up to a depth of nine feet) yielded the following data regarding water use and transpiration ratio (Table LXVIII).

TABLE LXVIII. WATER USE BY WHEAT UNDER UNIRRIGATED CONDITIONS AT PUSA
(Data of Leather, 1911)

	Water in lb./sq. ft. of soil surface	
	Series A	Series B
Initial	190·6	182·6
Rain	1·1	1·1
Evaporated	17·7	17·7
Remaining	120·9	137·5
Transpired	53·1	28·5
Transpiration ratio	313	237

The transpiration ratios for unirrigated wheat, under field conditions, were lower than those in pots where the water losses are made good at short intervals. The mean quantity of water used in transpiration was 40·8 lb./sq. ft. (8 inches) and for evapo-transpiration, 58·5 lb./sq. ft. (11 inches). The data given in the Table also show that stored soil moisture was the main source of moisture supply; the contribution of seasonal rainfall was negligible.

Computations of water requirements from irrigation experiments in the field require accurate determinations of three components: (i) the stored moisture, (ii) the seasonal rainfall, and (iii) the depth of irrigation water. Unfortunately, the data from the old irrigation experiments do not furnish information on all of these components. In one of the recent experiments at the I.A.R.I. where the sources of moisture supply were measured, the water requirements were found to be about 15 acre inches (Table LXIX) for a wheat crop which produced 35·6 md. grain and 78·1 md. straw per acre. The evapo-transpiration ratio was found to be 349.

TABLE LXIX. ABSOLUTE WATER REQUIREMENTS OF WHEAT AT DELHI
(Data of Pandey and Singh, 1958)

	Acre-inch	Percentage contribution	
Stored soil moisture	3·08	20·4	
Rainfall (seasonal)	2·02	13·3	
Presowing irrigation	4·00	26·5	66·3
Postsowing irrigations	6·00	39·8	
Total	15·10	100·0	

The stored soil moisture contributed about one-fifth of the total water used. It was found that the contribution of stored moisture was masked by a heavy presowing irrigation (four acre-inches) and could be still higher if a lighter soaking was given.

Conservation of soil moisture. It may be noted that stored soil moisture is the main source of moisture supply for the unirrigated wheat which covers 60 per cent of the total area under wheat in India. Stored soil moisture contributes substantially towards meeting the water needs of the crop even when other sources of moisture supply, i.e., irrigation and seasonal rainfall, are available. It is, thus, important that sound practices of soil management should be adopted to conserve the maximum amount of moisture during the monsoon season. Experimental work carried out at the dry farming research stations in India has been reviewed by Kanitkar (1944). The results emphasize the importance of cultural practices for moisture conservation.

The basic factor in moisture conservation is fallowing. However, this alone does not help. The land must be bunded to check run-off and it must be given cultivations to increase its water intake. The schedule of cultivations depends on the soil type and the distribution of rainfall. On sandy or medium-loam alluvial soils in the north, the soil should be opened up by ploughing before the onset of the monsoon. Ploughings should also be given during the rainy season, for the surface of the soil may be compacted under the impact of the beating rain drops and a hard crust may be formed on the surface if the soil remains undisturbed and is allowed to dry. The intake of water in the compacted soil is decreased and the rain water evaporates without adding to the soil moisture reserve. The effect of ploughing on the yield of wheat crop is clearly demonstrated by the following results of an experiment conducted at Kanpur and reported by Howard and Howard (1909).

Particulars	*Yield of wheat grain*
Portion ploughed in July	1,630·7 lb./acre
Portion unploughed till September	983·4 ,,

Though the beneficial effects of ploughing may be partly due to soil recuperation and better weed control, yet a part of the increase in yield may be ascribed to conserved soil moisture. This conclusion is substantiated by the results obtained at Rohtak (Table LXX).

TABLE LXX. EFFECT OF CULTIVATION ON THE CONSERVATION OF SOIL MOISTURE AT ROHTAK, YEAR 1937–38
(Data of Kanitkar, 1944)

Treatments	Moisture percentage in successive soil layers (in feet)					
	0–1	1–2	2–3	3–4	4–5	5–6
Stirred	16·21	16·52	14·84	15·17	13·27	8·83
Unstirred but weeds removed	15·29	12·67	14·43	14·20	11·95	9·61
Unstirred	16·13	7·73	9·23	10·60	10·70	8·42

In the post-monsoon period every ploughing should be closely followed by planking to conserve the soil moisture by reducing the surface exposed to the atmosphere and by breaking clods.

The medium-heavy black cotton soils cannot be stirred frequently as they remain wet during the monsoon season. However, the cracks developed in these soils during summer help to compensate for their otherwise low permeability and for fewer cultivations. In fact, in low-lying areas and in embanked fields of Jabbalpur and neighbouring districts no cultivation can be given during the rainy season, nor is it perhaps necessary as far as soil-moisture storage is concerned. In contrast, in areas of deficient rainfall in Sholapur and Bijapur, the soil may not attain field capacity in deeper layers. Such areas are, therefore, assigned to *rabi* (September to January) *jowar* rather than to wheat.

Importance of irrigation for wheat cultivation in India. The foregoing discussion on the importance of stored soil moisture for the cultivation of wheat under unirrigated conditions, does not imply that the moisture is adequate for the best wheat yields or is optimum for all or even most conditions. As the plants grow, the soil moisture in the surface layers of the soil is depleted, and they are forced to draw upon the moisture in the deeper layers. It is well known that the activity of the absorbing roots decreases with depth. The supply of moisture to plants does not generally keep pace with the optimum moisture requirements for growth, particularly at the critical periods. If the winter rains are good and well distributed, they supplement the stored soil moisture and lead to bumper harvests. However, these rains are often inadequate and undependable; as a result, the crop is subject to periodic partial failures, particularly on soils of low-moisture storage capacity. Thus, the provision of irrigation is the best means of moisture control for assured and high yields. The conserved moisture is, of course, quite important under irrigated farming too, for it reduces the demands on irrigation. In this connection, the results of an earlier irrigation experiment in the Punjab (Howard and Howard, 1909) may be cited which show that newly opened fields required more irrigation than old cultivated fields. Evidently the moisture stored in the soil was inadequate in the former case.

There is evidence to show that wheat responds to irrigation, both on the alluvial and on the medium black soils. Chaturbedi (1945) reported that a single irrigation of three inches depth applied 40 days after sowing, doubled the yield at Barabanki (U.P.) and gave three times the yield in the drier district of Bulandshahr (U.P.), as compared with no irrigation. On medium black soil at Obedullagunj (M.P.) one irrigation increased the yield from 11·5 to 14·6 md. per acre (Anon., 1959).

Irrigation of wheat is particularly important in North India where both the temperature and the length of the growing season are favourable for wheat, but the soils are light and have low moisture-storage capacity. Irrigation by wells has been practised from time immemorial. The expansion of irrigation resources by the development of perennial canals in the last as well as the present century have played an ever-increasing role in the wheat cultivation. In 1955–56 season, 39, 46 and 56 per cent of the total area under wheat in the states of the Punjab, U.P. and Rajasthan, respectively, was irrigated.

Irrigation requirements of wheat: For the efficient utilization of irrigation resources, it is essential to know the frequency and the depth of irrigations to be applied. A brief review of the work on these aspects carried out in the Punjab and U.P. and at the I.A.R.I., New Delhi, is given below. Reference has also been made to the recent irrigation experiments on medium black soils.

PUNJAB : Simple irrigation experiments were started by the Irrigation Department as early as 1905-6. The earlier work has been summarized by Howard and Howard (1909). The main conclusions which emerged from these studies were that cultivators wasted too much water and that economy in the water use was possible: (i) by irrigating each *kiari* (plot) separately and by smoothening the soil surface with a *sohaga* (plank) before irrigation instead of applying water to the field in cloddy condition, and (ii) by applying two irrigations to wheat on old cultivated fields and three to four to wheat on newly broken-up fields.

The Department of Agriculture, Punjab, conducted a large number of irrigation experiments on wheat at Lyallpur from 1931–32 onwards. A summary of the results of the work up to 1939-40 is presented by Khan and Dhesi (1941), who concluded that two irrigations were found to be adequate for grain production on rich land under good preparatory tillage. More irrigations increased straw weight, induced lodging and lowered grain yields. However, three irrigations appeared to be optimum on poor soils. Subsequent experiments have shown that three irrigations were required for late-sown crops also.

Further irrigation experiments on wheat were carried out under the I.C.A.R. Scheme on the water requirements of crops at Risalewala (near Lyallpur) from 1942 to 1947. On the basis of the results of these experiments, Khan and Nathu Ram (1947) reported that total water requirements of wheat at Lyallpur were 17·5 inches, including 3·5 inches of rain. They stressed the need for an early irrigation, preferably three weeks after sowing, giving the last irrigation before the middle of March and timing one irrigation in between. Delaying first irrigation decreased the yield (Nathu Ram and Singh, 1947). Nathu Ram and Mann (1946) inferred from their experiments on the delta and the depth of irrigation that with 10–12 inches irrigation water applied in two, three, four, five and six irrigations, it did not matter whether irrigations were frequent and light, or they were heavy and at longer intervals. The work in the I.C.A.R. Scheme also confirmed the earlier findings that planking the land before *rauni* (presowing soaking) economized water. The saving was 31 per cent (Singh, 1950). The reduction in the size of bed was also important; 1·64 inches less water was required with one-eighth of an acre plot than with half an acre plot, if the water discharge was 1 cusec (Khan and Nathu Ram, 1947).

Irrigation experiments were also conducted at Jullundur where four irrigations were found to be better than two or three irrigations, although the differences were small in magnitude.

UTTAR PRADESH: The early experiments mentioned by Howard and Howard (1909) indicated that monthly irrigations to wheat crop were the best. Mitra and Sabnis (1945) pointed out that wheat requires presowing irrigation of three to five inches depth, if monsoon has been weak and moisture inadequate, for germination. This irrigation carries the crop through germination and seedling phase, i.e., for about a month after sowing. One irrigation of three inches depth is needed for the vegetative phase which covers the period from end-November or early-December to January. The third irrigation of two to three inches is necessary at the beginning of heading stage (end-January or early-February). Thus, the total water requirement of wheat was found to be 8 to 11 inches exclusive of monsoon rains. According to Bhattacharya (1954), while two irrigations were required in the western U.P. one would do in the eastern parts. This is understandable in view of relatively wetter conditions in the latter region.

When a single irrigation is applied, the depth of irrigation becomes an important factor. Chaturbedi (1945) compared 0, 2, 3, 4, 5 and 6 inches depths and found that yield increased with the depth of irrigation up to three inches, remained steady up to four inches and then declined. The more economical use of water was with two inches depth as this gave 80 per cent of the yield obtained with three inches depth. Where more irrigations were applied, the effect of irrigation depth was masked. This is borne out by the results of Rao *et al.* (1957), who applied four irrigations of varying depth (60, 90 and 120 thousand gallons per acre per irrigation) and found that yield was not affected by variation in the depth of irrigation.

I.A.R.I., NEW DELHI: More than two irrigations during the crop season were hardly necessary for wheat variety N.P. 718 (Pandey and Singh, 1958), which is a shorter duration variety as compared with the Punjab wheats C. 518 and C. 591. With more irrigations the straw weight increased consistently while increased grain yields were obtained only in certain years. When the crop was sown after presowing irrigation and the rains were received at the heading stage, a single irrigation in the crop season carried the crop successfully to maturity. When the crop was sown on conserved soil moisture without presowing irrigation, three irrigations gave the best results.

A comparison of irrigation depth showed that three inches depth was adequate. If the field levels are good, even shallower irrigation of two to two and a half inches would meet the needs of the crop. This is explicable in terms of the moisture extraction pattern of the wheat crop. More than 80 per cent of the moisture used by wheat is drawn from the top two feet of the soil.

Observations made at the I.A.R.I. also showed that furrow or corrugation irrigation in wheat economized water and reduced lodging. This has opened up the possibility of increasing crop production on rich land by light irrigation during the critical stages. Studies on irrigation efficiency showed that presowing soaking dose of four inches depth raised the moisture content of the soil in the root zone (up to four feet depth) by one inch only, as the stored moisture in the subsoil was already high. This indicates the scope for saving of irrigation water.

It may be summed up from the work on the irrigation of wheat conducted so far that, except in special circumstances, two irrigations during the crop season are adequate after a normal monsoon. The first irrigation may be given when the tillering is over, when the crop is sown after a presowing soaking. The second irrigation should be applied at the heading or the bloom stage. In either case, just enough water should be applied to fill the soil moisture deficit and to restore the moisture content of the soil to field capacity. This requirement is normally met by applying irrigations of medium depth (three inches).

In special cases, such as light and poor soils, late sowings, late-maturing varieties, rainless winters and omission of presowing soaking, it would be necessary to apply three irrigations. The third irrigation must be light and, as far as possible, given on days or nights when wind velocity is low, so that lodging is prevented. No irrigation need be given to wheat after the first week of March, when the crop has passed into maturation phase. If reliable forecasts of wind velocity could be broadcast to the farmers from end of January to early of March, it might help them to time the third irrigation. Mention may be made here of the results of the irrigation-cum-manurial experiments conducted at six centres in India during 1953–54 to 1955–56 under the Fertilizer Use Project (Anon., 1959). It appears from these results that two or three irrigations were the optimum on medium black soil in Madhya Pradesh. However, recent experiments at Hoshangabad (M.P.) indicate that yield continued to increase up to four irrigations (Ekbote and Engle, 1959).

Irrigation in relation to manuring: It has been well established that fertilizers and manures which stimulate growth lead to efficient use of water. However, as the dry matter or leaf surface increases, the total transpiration also tends to go up and the soil moisture is depleted comparatively earlier. The response of irrigated wheat to nitrogen was 60 per cent that of unirrigated wheat (Yates *et al.*, 1953). In practice, under rainfed conditions the crop is rarely manured. In this connection the work of Zook and Weakly (1950) abroad may also be cited. They found that, on account of deficient moisture, manuring decreased grain yield though it increased the straw weight. In such cases, application or irrigation water at the critical period, if available, is expected to enhance the utilization of nitrogen and the two factors may show a positive interaction. However, a further increase in irrigation may not necessarily enhance nitrogen effect, as any increase in straw may not be reflected in increased grain yield on account of the limiting influence of factors such as season and lodging. Evidence in support of this is furnished by the following data of an experiment (Table LXXI) conducted at the I.A.R.I. during 1958–59.

TABLE LXXI. EFFECT OF IRRIGATION AND NITROGEN ON THE GRAIN YIELD OF WHEAT (MD./ACRE)

Rain in inches	No. of irrigations	Nitrogen levels (lb./acre)		
		0	30	60
2·00	One	28·9	34·0	35·8
2·00	Two	29·8	35·8	37·7
2·00	Three	33·5	36·8	35·1

Heavy responses to nitrogen were recorded even with a single irrigation supplemented by two-inch rain received at the heading stage. The interaction between irrigation and nitrogen was not significant.

Irrigation-cum-manurial experiments under the Fertilizer Use Project have also shown that there was no significant difference in the response.

Influence of irrigation on other cultural practices: Under unirrigated conditions, the wheat crop is grown mixed with gram, barley, rape seed, mustard and linseed. Mixed cropping serves as an insurance against the vagaries of season, as one crop compensates for the loss of the other depending upon the season. Under well irrigation the crop is often sown mixed but under canal irrigation the wheat is generally grown pure.

Under unirrigated conditions, the field is fallowed in the preceding *kharif* season. Under irrigation, the bulk of area is fallowed but occasionally a maize crop may be taken before wheat is sown in the same year. With irrigation, there is considerable scope for the adoption of green-manuring on poor soils and for the adoption of double cropping with the use of fertilizers. Experiments at the I.A.R.I., New Delhi, have shown that with manuring, wheat crops yielding more than 25 md. per acre can be obtained easily after a normal crop of maize or sorghum in the preceding *kharif*.

Method of sowing depends on whether a crop is sown after a presowing soaking (*palewa* or *rauni*) or on conserved soil moisture. In the former case, the seed is generally dropped in furrows made by country plough (*kera* method) followed by planking. Some of the farmers broadcast seed on the moist surface of the soil, plough the land to cover the seed and, thereafter, plank the seed-bed. When the crop is sown without the presowing irrigation, the surface soil to a depth of three to four inches is generally dry at the time of sowing. As the optimum depth of sowing in wheat is only three inches, the seed has to be drilled and placed in the moist soil layer but without increasing the thickness of soil cover above the seed. This is ensured by drilling the seed in rows 10–11 inches apart (instead of sowing at nine inches as under irrigated conditions) so as to fill the furrows half way only. However, after sowing the furrows are left open, i.e., the field is not planked. Where the soil is sufficiently moist at soil surface, this method of sowing is not necessary. The seed rate used under unirrigated conditions is sometimes more and sometimes less than that used under irrigation (Howard and Howard, 1909; Roberts and Singh, 1947). This is because of two separate considerations. Under unirrigated conditions higher seed rate would appear to be desirable in view of decreased tillering, hazards of white-ant attack and less moisture in the surface layer of the soil for germination. On the other hand, under these conditions moisture may be inadequate to support a thick crop. Under irrigated conditions seed rate appears to depend on whether the crop is sown with or without a presowing irrigation. For example, in the south-eastern districts of the Punjab and in Delhi area where the crop is sown on conserved moisture (but is irrigated by well water about a month after sowing and receives 3–5 irrigations during the season) 80–100 lb. seed rate per acre is used as compared to 50–60 lb. in parts of northern India, where presowing irrigation is given. The higher seed rate appears to compensate for less tillering and covers to some extent the risk of damage from white-ants.

Mention has been made of the practice of omitting manuring under unirrigated conditions. If the subsoil contains enough moisture, as is usually the case, deep fertilizer application or an early application of a mobile fertilizer that is washed into the subsoil by late monsoon rains may increase the effectiveness of the fertilizer. Experiments on this aspect have not been carried out with wheat in this country but the work of Gliemeroth (1955) abroad points to the prospects of subsoil manuring under unirrigated conditions.

WEEDS AND THEIR CONTROL IN WHEAT CROP

Indian farmers pay extraordinary attention to the cultivation of the wheat crop, especially to seed-bed preparation, manuring and irrigation. In spite of that the weeds do enormous damage to this crop. Weeds directly deplete the soil of nutrients and moisture and compete with crop plants for light and thus reduce the crop yields. Indirectly, they cause damage to the crops by harbouring pests and diseases which reduce the net returns, by making the harvesting and threshing of crops more costly and laborious, and by lowering the quality and reducing the value of the produce because of the admixture with weed seeds. It has been estimated that losses caused by weeds in wheat crop range from 7 to 50 per cent, depending on the intensity of weeds and the dominant species present. Taking a conservative figure of 10 per cent as the average loss in yield and total production of wheat in India to be eight million tons, the total loss to the nation works out to Rs. 313 million annually.

Wheat is a close-sown crop. This fact works two ways: while high population and close spacing offer high degree of competition to the weeds, inter-row cultivation by mechanical means is barely possible and, if practised, may harm the root system of the wheat crop. Therefore, hand weeding is generally practised for the weed control in this crop. Hand weeding, however, is costly and laborious and large acreage is left unweeded. Weeds which establish early and are not removed cause considerable damage to the crop.

Weeds associated with wheat crop. The most common weed to be noticed in the early stages is *Cyperus rotundus* (*motha*). The growth of this weed is, however, soon arrested due to fall in winter temperatures and, therefore, much harm is not done by this weed to the wheat crop. Later on other weeds come up fast and compete with the crop. Of these four annual weeds, namely, *Chenopodium album* (*bathua*), *Asphodelus tenuifolius* (*piazi*), *Anagallis arvensis* (*krishan nil*) and *Carthamus oxyacantha* (*pohli*) are the dominant ones. These are almost universally distributed and are the most serious competitors of this crop in northern India. On the basis of survey carried out in wheat fields at several locations in the farm of the Indian Agricultural Research Institute and in the 20 villages in Delhi State the following weeds, listed in order of severity, were found associated with wheat crop.

Botanical name of the weed	Local name
Chenopodium album L.	*Bathua*
Asphodelus tenuifolius Cavn.	*Piazi*
Carthamus oxyacantha Bieb.	*Pohli*
Anagallis arvensis L.	*Krishan nil*
Convolvulus arvensis L.	*Hiran khuri*
Fumaria parviflora Lam.	*Pitpapra*
Spergula arvensis L.	*Gajra*
Euphorbia dracunculoides Lam.	*Chhoti dudhi*
Launaea aspleniifolia Hk. f.	*Jungli gobhi*
Malva parviflora L.	—
Melilotus alba Lam.	*Senji*
Melilotus parviflora Desf.	*Senji*
Vicia sativa L.	*Chatri*
Vicia hirsuta Koch	*Chutrimatri*
Medicago denticulata Willd.	*Maina*
Lathyrus aphaca L.	*Matri*
Cynodon dactylon Pers.	*Dubh*
Cyperus rotundus L.	*Motha*

Most of these weeds except *Anagallis arvensis*, *Carthamus oxyacantha* and *Launaea aspleniifolia* germinate and mature with the crop and, therefore, compete throughout the life-cycle of the crop plant. *Anagallis arvensis* has a short life span and, therefore, competes mostly in the early stages. *Carthamus oxyacantha*, perhaps the most obnoxious weed of this crop, germinates about the end of November and becomes a serious problem at the time of harvesting. Similarly, *Launaea aspleniifolia* generally appears from December onwards and competes mostly in the later stages of the crop. Leguminous weeds like *Melilotus* spp., *Vicia* spp. and *Lathyrus* spp. appear about a fortnight after the date of sowing of the wheat. They are less harmful than other weeds in the sense that they take their nitrogen from the atmosphere. However, they do compete for soil moisture, space and sunlight.

Nature of weed–wheat competition. When environmental conditions are favourable for the crop growth, wheat plants may shade the weeds and crowd them out. Only those weeds, with growth habits similar to those of wheat, survive the competition of the vigorous and fast-growing crop and the reduction in yield in such cases may be very little. If conditions are less favourable to crop growth, particularly on lands of low fertility, the loss in yield may be 50 per cent or more.

The nature of weed competition with wheat is clearly brought out in Table LXXII (Verma and Bharadwaj, 1957).

TABLE LXXII. CROP–WEED COMPETITION IN WHEAT

**Mean no. of weeds per acre	**Mean no. of wheat plants per acre
1,942,776	242,800

**Mean represents average of 23 demonstration plots laid out in the Intensive Cultivation Scheme of the I. A. R. I.

Evidently, a very large number of weed plants compete with a comparatively smaller number of wheat seedlings. As the growth of wheat is rather slow until the tillering phase is over, the weeds get an initial advantage over wheat. Thus the weed—wheat competition is more acute in the earlier stages of crop growth. If this competition is not eliminated by cultural or chemical methods, it leads to heavy reductions in the yield of the wheat crop.

Losses due to weeds. Several estimates of losses due to weeds in cereal crops have been made in European countries. The most comprehensive of these were the ones made by Korsmo (1930, 1932) in Norway, who carried out 3,552 simple experiments during the period 1916–1923 and showed that the average yield increase from various methods of weed control was 21·2 per cent. In Germany, Wiede (1950) calculated that the gain in yield as a result of weed control by 2,4-D was about 21 per cent. In the U. K., Blackman *et al.* (1949), averaging the results of three years' experiments with several weed-killers, obtained 23 per cent gain in yield.

In India, research on weed control is of very recent origin. Pande (1953, 1954) concluded that the removal of weeds from wheat field increased grain yield in relation to the degree of weed-infestation, the effect being more marked under low than under high fertility status of the soil. Verma and Bharadwaj (1957), on the basis of demonstration plots in farmers' fields, found that control of weeds by 2,4-D gave an average increase of 25·3 per cent in the yield of wheat crop. The increase in yield was found to be highly correlated with the degree of weed infestation.

Methods of weed control. The various methods of weed control practised in wheat crop are discussed below.

I. *Mechanical methods:* 1. HAND PULLING AND HOEING: Hand pulling is seldom practised on large scale for wheat as it is a very laborious and time-consuming operation. In India, the most common method of weed control is hand weeding with *khurpi*. As *khurpi* has a small handle, it can be used only in the squatting position. To increase the output of work and make the operation less tiresome, efforts have been made recently to introduce various types of hand hoes fitted with long handles. These can be worked in the semi-erect to erect posture. However, *khurpi* still remains the most popular device for hand weeding, possibly because of its superiority in the quality of work. Since wheat is a close-sown crop, larger implements cannot be used for inter-row cultivation as they are liable to injure the wheat plants.

2. TILLAGE: Experiments carried out by several workers (Cates and Cox, 1912; Brenchley, 1915; Stewart, 1947) have shown that the chief purpose of cultivation is the control of weeds. The large number of preparatory cultivations the farmers generally give to the wheat field indicates the importance of tillage as a weed-control measure. Thorough preparation of seed-bed reduces initial infestation by weeds and puts the crop in an advantageous position to compete with later germinating weeds. In the Punjab, the practice locally known as *dab* is practised mainly to remove weeds. It consists in preparing the seed-bed and leaving it undisturbed for a week or ten days. During this period a large number of weeds come up. The land is then ploughed once more and the sowing done. This operation destroys most of the germinated and germinating weed seeds and helps a great deal in raising a comparatively weed-free wheat crop.

3. INTERCULTURE: Harrowing with bar harrow is sometimes recommended in fields badly infested with weeds but when the latter are still quite young. This is done with the object of destroying weeds before their root systems have been well established.

Other bullock-drawn implements are also sometimes used in different parts of the country. Perhaps the most common implement in this category is the *bakhar*. Another implement known as the 'Oudh plough' (a country plough with a narrow *phal*) is also used as an inter-row cultivator for this crop in some areas. But all these implements suffer from the disadvantage that they leave the weeds undisturbed in the wheat rows. Moreover, they are liable to injure the root system of the wheat crop.

II. *Cropping methods:* A carefully planned rotation of crops often proves very effective in controlling weeds. Chandnani *et al.* (1960) found that the weed growth in wheat was increased in the absence of a fallow or a land-cleaning crop like potato in the rotation.

Some success in keeping the weeds under check has also been obtained by timely sowing and by increasing the seed rate. Godel (1935) recommended that for general use, weed menace in cereals could be greatly reduced by seeding the crops shallow, early, at heavier seed rate and with commercial fertilizers. Experiments at the I.A.R.I. have, however, shown that competition from weeds was greatly reduced if the wheat crop was sown slightly late so as to allow most of the *rabi* weed seeds to germinate which got destroyed during seed-bed preparation. Similar effect was observed when a slightly heavy seed rate was used. The data are presented in Table LXXIII (Verma and Bharadwaj, 1957).

Both the weed population and the dry weight of weeds were reduced as the seed rate was increased. By delaying the sowings, however, the weight of weeds was considerably reduced, but no reduction was obtained in the weed population. Besides, the dry weight of all weeds, in general, is reduced under late sowings due to a sharp fall in temperature in the month of November. Since sowings later than

TABLE LXXIII. WEEDS IN WHEAT CROP

Seed rate per acre (in lb.)	No. of weeds per 12 sq. ft.	Dry weight of weeds per 12 sq. ft. in gm.
	Effect of seed rate	
50	32·0	27·5
70	30·4	27·1
90	26·0	21·4
	Effect of time of sowing	
November 1	27·6	45·7
November 12	31·7	24·8
December 1	29·9	4·2

middle of November may sometimes cause a reduction in the yield of wheat crop, a sowing date about the middle of November appears to be the most appropriate for Delhi area.

III. *Chemical control:* Chemicals were first used for control of weeds in cereals about 60 years ago. In 1895, scientists in France, America and Germany discovered that a dilute solution of copper sulphate when sprayed on to cereal crops killed *Sinapis arvensis*, the most serious weed of cereals in Europe, without injuring the cereals. A good deal of progress in this field has been made since then. A brief description of the chemicals used for controlling weeds in wheat crop is given below.

(a) INORGANIC COMPOUNDS: The first commercially developed herbicides were inorganic chemical compounds. Relatively few of these are now in use, largely because of the high dosage required to control weeds. Though many chemicals, viz., sodium chloride, nitric acid, calcium cyanamide, ammonium sulphate, sodium nitrate and kainite were tried, copper sulphate was generally the most used. Brenchley (1920) recommended a 3 to 5 per cent solution of this salt at 50 gallons per acre. Later, Rabate (1927) in France, Korsmo (1932) in Norway, and Blackman and Templeman (1936) in England established the effectiveness of sulphuric acid for weed control in cereals.

The next discovery in the field of chemical weed control was that of 2,4-dinitrophenol (DNP) and 3,5-dinitro-o-cresol (DNC) by French workers in 1932. These chemicals were later extensively used for weed control in cereals in the U.K. and Netherlands.

The selectivity of the weed killers mentioned so far is dependent on the differences in the habit of growth of the cereals and the weeds. Cereals because of their waxy, narrow, upright leaves and their protected growing points are not vulnerable to chemicals. But annual weeds that have flat leaves and exposed apical growing point are most highly susceptible to the effect of these weedicides.

(b) ORGANIC COMPOUNDS: Of the organic compounds, phenoxy acids have been found suitable and have been widely used as selective herbicides; they are discussed in some detail here in the following pages.

PLATE 88. Transportation of sheaves of wheat to the threshing floor

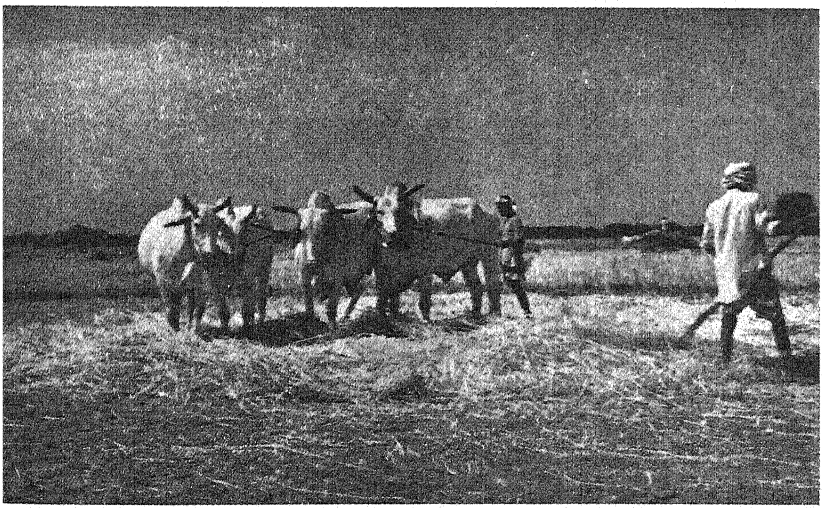

PLATE 89. Wheat threshing

Plate 90. Winnowing

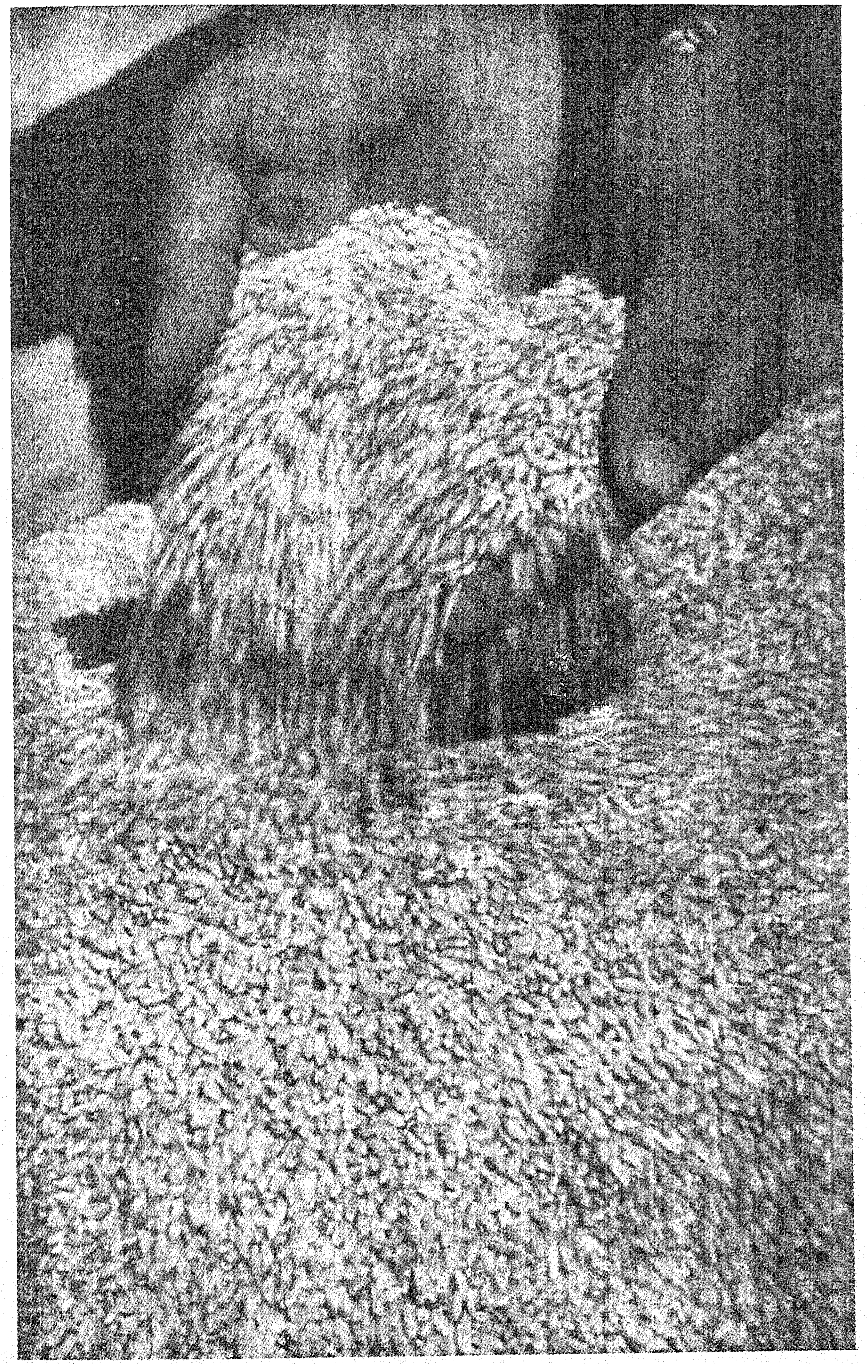

PLATE 91. Wheat grain in bulk

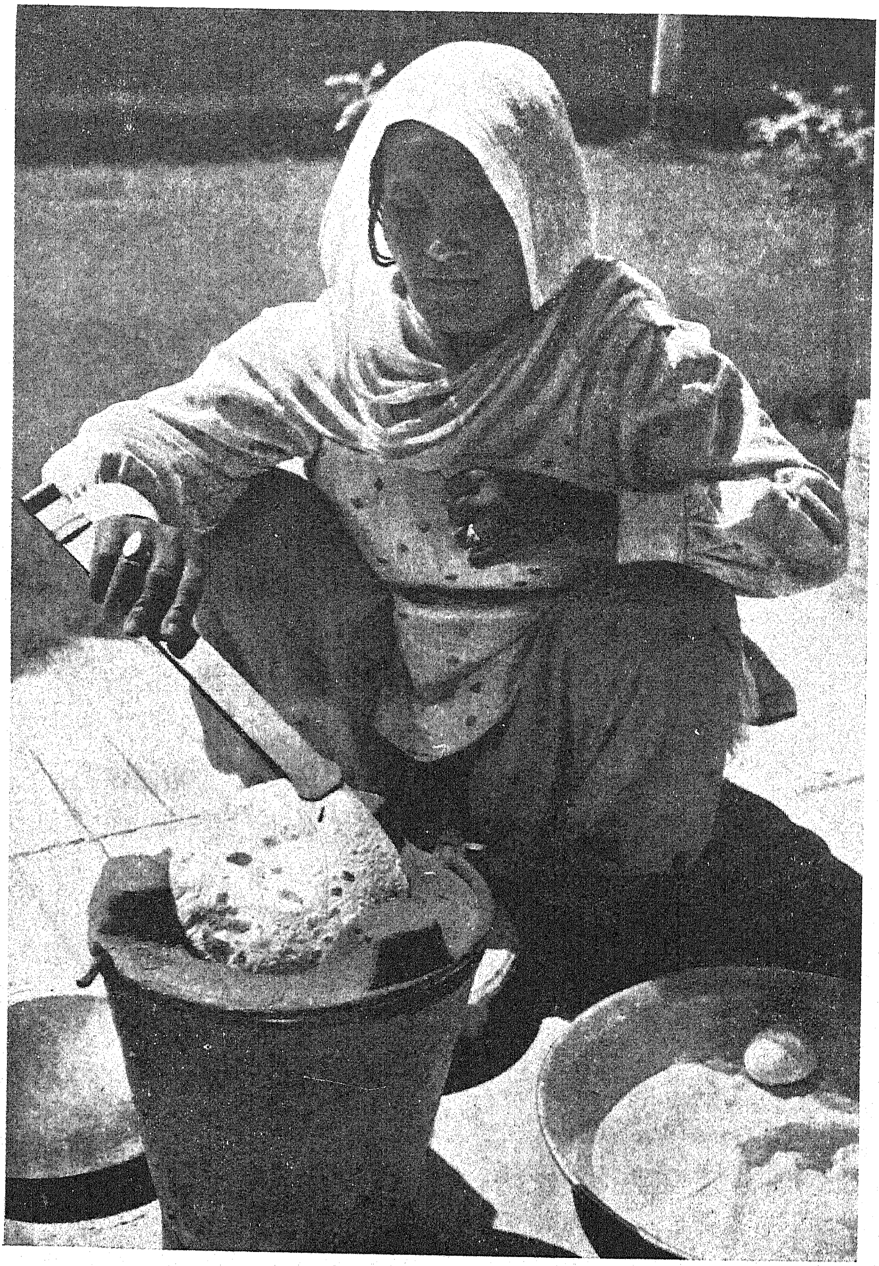

PLATE 92. Baking *chapattees* (unleavened bread), the most common form in which wheat is consumed in India

Phenoxy acids: The discovery reported by Slade *et al.* (1945) that certain growth-regulating substances are selectively toxic to plants mainly because they affect the metabolic processes of some plants leaving those of others unaffected, ushered in a new era in the field of chemical weed control. It led to the development of the two most important herbicides yet discovered: 2-methyl, 1-4-chlorophenoxyacetic acid (MCPA) and 2,4-dichlorophenoxyacetic acid (2,4-D). These herbicides are now used for the control of weeds growing in many millions of acres of cereal crops in Europe and America.

These two chemicals were found to be superior to any that had been previously used for cereals, primarily because they were truly selective in their action, and also because they were effective in such small amounts, were neither poisonous nor corrosive and could be applied either as dust or spray.

Wheat crop is sensitive to 2,4-D or MCPA in the germinating and in the seedling stages. The plants, however, gain considerable resistance by the time tillering is complete. At that time, the plant is about six weeks old. The plants again become susceptible during the early boot stage, and they remain susceptible throughout the period of pollination. The rates recommended range from 4 oz. to 1 lb. acid equivalent per acre applied six weeks after sowing.

Field experiments carried out in the Division of Agronomy, Indian Agricultural Research Institute, have clearly shown that sodium salt of 2,4-D at 8 oz. a.e. per acre, applied six weeks after planting brings about fairly satisfactory control of weeds in wheat crops. No apparent injury or reduction in yield were obtained when the doses were raised up to 2 lb. a.e. per acre. Results are given in Table LXXIV (Verma and Bharadwaj, 1957).

TABLE LXXIV. EFFECT OF POST-EMERGENCE SPRAY OF 2,4-D ON THE YIELD OF WHEAT

Treatment	Yield of grain in md./acre		
	1955–56	1956–57	1957–58
Control	16·1	10·7	15·9
2,4-D at 8 oz. a.e./ac.	16·4	12·2	20·5
2,4-D at 1 lb. a.e./ac.	17·4	12·8	20·6
2,4-D at 2 lb. a.e./ac.	17·1	11·4	19·1
Hand weeding	19·5	12·9	21·6
Hoeing with bullocks	17·3	11·3	16·8

On the basis of these results, demonstration plots were also laid out in villages covered by the Intensive Cultivation Scheme of the Indian Agricultural Research Institute, New Delhi, during 1956–57 and 1957–58. Since the fields were severely infested with *Asphodelus tenuifolius*, a slightly higher rate (1 lb. a.e. per acre) of the sodium salt of 2,4-D was used. Applications at this rate gave effective control of *Asphodelus tenuifolius* and other *rabi* weeds, and thus added appreciably to the yield of the crop. The results are given briefly in Table LXXV.

TABLE LXXV. EFFECT OF 2,4-D SPRAY ON THE YIELD OF WHEAT GRAIN IN CULTIVATORS' FIELDS

Year	Population of weeds (Mean per 4 sq. ft.)		Yield of grain (Mean in md./ac.)	
	Control	Treated	Control	Treated
1956–57 (Mean of 6 demonstrations)	182·4	21·2	15·6	19·4
1957–58 (Mean of 23 demonstrations)	178·4	6·3	12·7	15·4

The extra yields obtained in 1956–57 and 1957–58 were 3·8 and 2·7 md. respectively. The cost of weedicide application was Rs. 8 per acre as against the total profit of Rs. 37 per acre, leaving a net profit of Rs. 29 per acre. Thus, chemical weed control was found to be very remunerative in the case of wheat crop.

2,4-DB and MCPB: Recent interest in the chemical control of weeds has led to the discovery of large number of newer chemicals; the most important of these in relation to wheat are 2,4-DB (2,4-dichlorophenoxybutyric acid) and MCPB (2-methyl-4-chlorophenoxybutyric acid). Wain (1955 a, b) found that plants differ in their ability to convert an inactive substance, such as 2-methyl-4-chlorophenoxybutyric acid (MCPB) into an active substance MCPA and that, in consequence, it is possible to obtain greater selectivity by using MCPB rather than MCPA and 2,4-DB rather than 2,4-D. Preliminary work (Carpenter and Soundy, 1955; Wain, 1955a). showed that MCPB and 2,4-DB are less toxic to cereals than the corresponding acetic acids and yet are as toxic to several weed species. Recent studies conducted (Verma and Bharadwaj, unpublished) on the relative performance of 2,4-D and MCPB applied at different stages of crop growth are summarized below.

TABLE LXXVI. DEFORMITIES CAUSED IN WHEAT CROP BY SPRAYING 2,4-D AND MCPB AT 1 LB. A.E. PER ACRE

Treatment	Time of application after sowing wheat (in weeks)	Percentage of deformed ear-heads
2,4-D	3	57·0
	6	nil
	3 & 6	73·5
MCPB	3	nil
	6	nil
	3 & 6	nil
2,4-D MCPB	3 6	63·0
2,4-D MCPB	6 3	nil

COSTS OF CULTIVATION

Studies on the economics of growing wheat have yet to be conducted on a fairly representative and nation-wide scale. Investigations so far conducted under farmers' conditions in the villages in the Intensive Cultivation Scheme Area attached to the Indian Agricultural Research Institute and elsewhere seem to indicate that while the costs of cultivation per acre tend to increase as the size of the holding decreases, the average costs of production per maund of grain show an opposite trend. Due to the higher intensity of production operations including tillage on the smaller holdings the costs per acre rise, but the higher costs are more than offset by the higher productivity per acre on the smaller holdings.

The following data (Table LXXVII) gathered in the course of Farm Management investigations conducted by the I.A.R.I. on 64 holdings randomly selected from different size categories during the *rabi* season of 1958–59 will serve to illustrate this point.

TABLE LXXVII. AVERAGE COST OF CULTIVATION OF WHEAT ON FARMERS' HOLDINGS, 1958–59

Size-group of holding	Cost per acre (Rs.)	Yield of grain per acre (md.)	Cost per md. of grain (Rs.)
Less than 5 acres	318·87	17·25	18·47
5 acres to less than 10 acres	286·89	16·13	17·77
10 acres to less than 15 acres	286·40	14·97	19·12
15 acres and above	258·79	13·45	19·23

Similar studies conducted a year earlier at the farm of the Indian Agricultural Research Institute brought out the following information:

Cost per acre (Rs.)	276·04
Av. grain yield per acre (md.)	17·74
Cost per md. of grain (Rs.)	15·56

The costs per acre at the Indian Agricultural Research Institute Farm are more or less at par with those observed on the larger-sized holdings. Due to higher yields obtained through application of scientific methods, the cost of production per maund works out to a much lower figure, even with the considerably higher wages paid to labour at the Institute's Farm.

Productivity of human and bullock labour. Studies in productivity of resources, specifically human and bullock labour, employed in the production of wheat in the same sample of farms, have shown on a *ceteris paribus* assumption that while 1 per cent increase in the use of human labour contributes to 0·52 per cent increase in the value of wheat crop produced, an increase in bullock labour tends to diminish the produce. But simply, these studies indicate the profitability of intensification of the use of human labour and reduction in the use of bullock labour in the cultivation of wheat at the present level of technology in these areas.

The figures (Table LXXVIII) indicate that bullock labour is the largest constituent of the costs of growing wheat and rational efforts at economy on this item would certainly play a significant role in reducing the costs. As the size of the holding increases, the cost of seed begins to assume greater importance. Another noticeable feature is the curious lack of emphasis on the use of manures and fertilizers in the larger holdings.

TABLE LXXVIII. PERCENTAGE SHARE OF VARIOUS COMPONENTS OF COSTS OF PRODUCTION OF WHEAT ON FARMERS' HOLDINGS, 1958–59

Components	Size of group of holdings			
	Very small	Small	Medium	Large
Bullock labour	46·6	45·6	46·2	45·5
Human labour	24·4	25·2	24·5	22·3
Land	12·4	13·5	13·9	16·3
Manures and fertilizers	8·1	5·6	5·6	3·5
Seed	5·8	6·9	6·9	7·2
Irrigation	0·3	0·3	0·3	0·2
Other costs	2·4	2·9	2·6	5·0

There appears to be a pressing need for well-planned studies on the economics of wheat growing and production.

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XV

WHEAT STRAW

Wheat straw (*bhusa*) is an important cattle feed in India. Due to the limited land holding which the average Indian farmer has at his disposal, special fodder crops cannot be grown to feed his livestock. Further, 70 per cent of the cultivable area in India is still under rainfed or unirrigated conditions and as such fodder crops on such lands are not economical. Consequently, the Indian farmer grows crops which yield both grain and straw. This situation naturally demands the cultivation of such varieties which give good returns both with regard to grain and straw.

Under Indian conditions the straw yield of wheat per unit area is two to three times that of the grain; soft, pliable straw is preferred over stiff straw with strong nodes which does not form good *bhusa*. Hence, farmers have a liking for tall-growing wheats. With the increasing utilization of fertilizers to step up food production in the country, there is bound to be a demand for short- and stiff-strawed wheats by some farmers. For this, work is already in progress at different breeding centres in the country.

The constituents of the wheat *bhusa* were analyzed by Sen (1928) and more recently by Lander (1942). The results obtained by Lander are summarized below.

	% on dry weight		% on dry weight
Ash	14·07	Sodium (Na_2O)	0·28
Fats	1·02	Potassium (K_2O)	1·25
Crude fibre	39·55	Phosphoric acid	Nil
Protein	2·39	Manganese (MgO)	Nil
Soluble carbohydrates	42·97	Sulphate (SO_4)	0·47
Soluble residue	10·94	Water-soluble chloride	0·17
Iron (Fe_2O_3)	0·16	Iodine	4×10^{-5} gm.
Aluminium (Al_2O_3)	0·15		
Calcium (CaO)	0·42		

With regard to the food value of the wheat straw as expressed in units, Sen (1938) found that it has 64·5 units as compared to 100 units present in wheat grain.

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XVI

IMPLEMENTS AND MACHINERY

It is well known that agricultural machinery and implements for wheat culture have received considerable attention in the advanced countries of the world where the operations are now mostly mechanized. It is, however, not so widely appreciated that most of the agricultural machinery as well as cultural implements were originally developed as animal-drawn or animal-operated versions and they had already reached a high state of efficiency and development much before the powered prime mover, viz., the agricultural tractor, appeared on the scene. Even to this day in many of the European countries and in Latin America, animal-drawn implements and machinery are still widely in use. The farmers in India, however, have been slow in adopting the improved implements and wheat farming is done mostly by animal-drawn indigenous implements of rather primitive design which have retained the same basic pattern unchanged for several centuries. An all-India survey of common indigenous agricultural implements has revealed that there are over 600 distinguishable types of implements in use in India. This does not include improved implements as, for instance, furrow-turning ploughs.

TILLAGE OPERATIONS WITH INDIGENOUS IMPLEMENTS

The chief indigenous implement for cultivation consists of the indigenous plough; this, basically, is a heavily constructed, single-tyned, deep-working cultivator made of wood. The share is usually made of steel. The action of the plough consists of loosening up the soil to a depth of about three to four inches. The main working part of this plough consists of a tapered, triangular, wedge-shaped block of hard wood, called the shoe; the cutting or tearing of the soil is achieved through an iron share or point which is fixed on the top of this triangular wedge of wood. The shoe is fixed at an angle with the body, and with the forward movement of the plough it penetrates the soil and leaves a V-shaped furrow, which widens as the wedge-shaped shoe advances through the soil. The main defects of this plough are that it leaves an uncut portion between the furrows, the soil slice is not inverted and the surface trash is not buried. The depth of working seldom exceeds three to four inches.

The working of the indigenous plough depends on the working angle of the share with the ground surface, which is mainly controlled by adjustment of the distance of the hitch point between the plough beam and the yoke. For greater penetration the yoke is moved forward along the beam or *vice versa*. Repeated operations are required in order to ensure that the ground is loosened all over the field to a uniform depth without leaving uncut portions in between the furrows. The life of the indigenous plough depends on several factors, i.e., the type of wood used, type of land

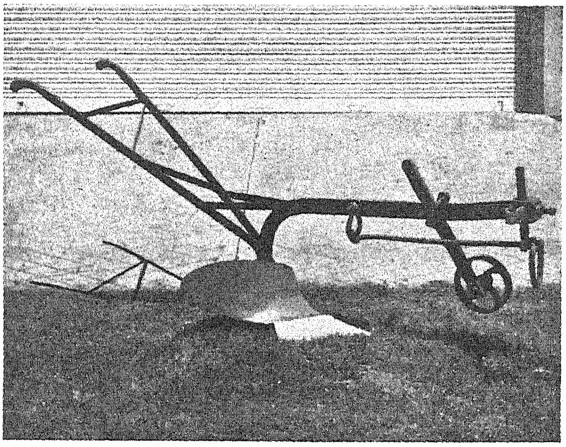


PLATE 93. Mould board plough—operated by one man and two pairs of bullocks, it can cover an acre in eight hours

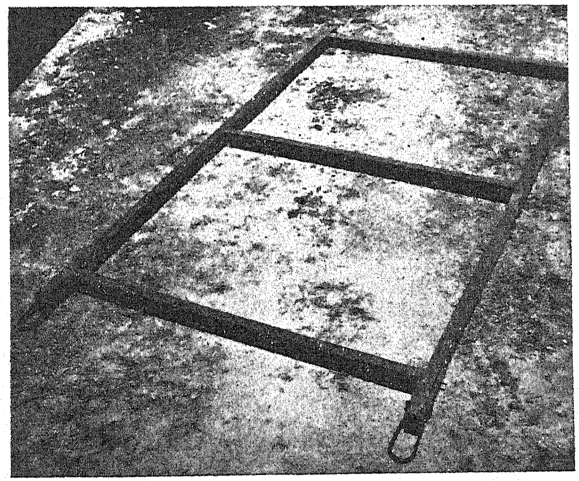


PLATE 94. Float for smoothening and finer levelling of land

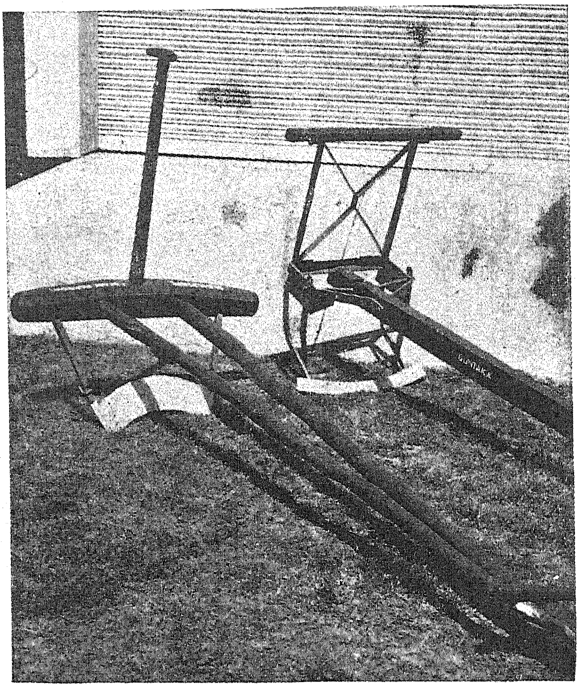


PLATE 95. Blade harrows. *Bakhar* (Left) and *Guntaka* (Right)

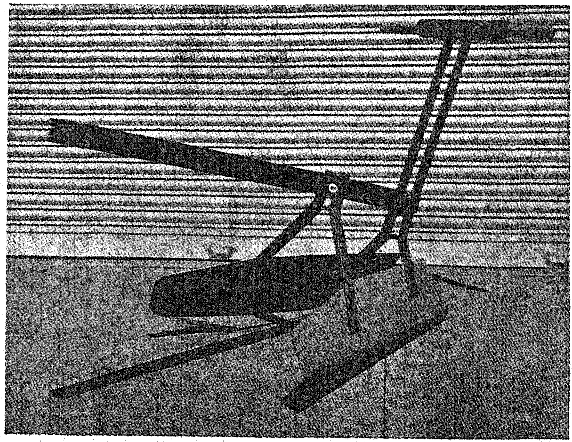


PLATE 96. Bund former

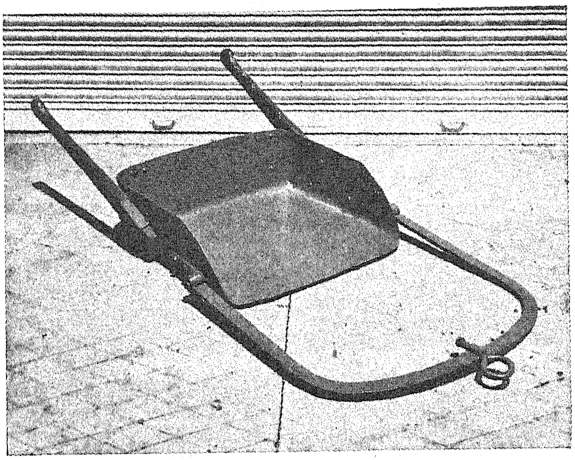


PLATE 97. Buck scraper for land levelling

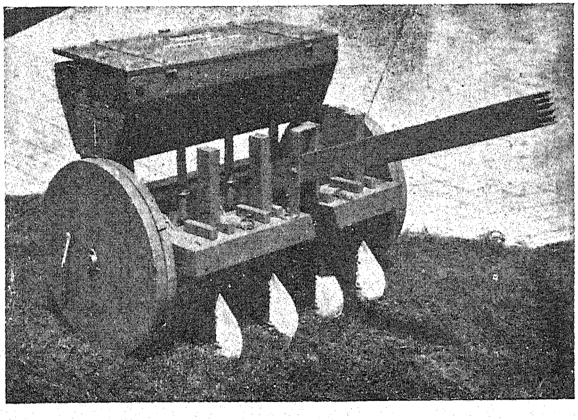


PLATE 98. Wooden seed drill by which seed rate can be controlled within a small range

PLATE 99. Seed drill by which seed rate and depth of sowing can be adjusted

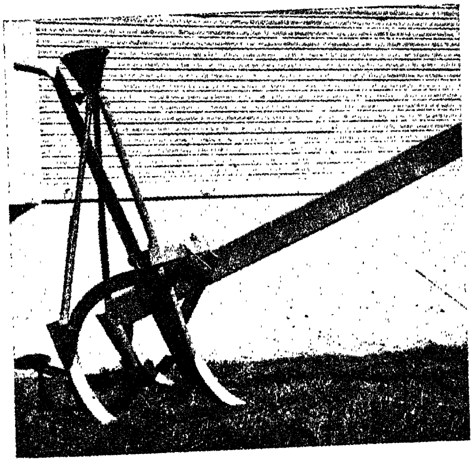


PLATE 100. Three-tyne cultivator with seed spout attachment which can be used for seed-bed preparation, row sowing and also interculture

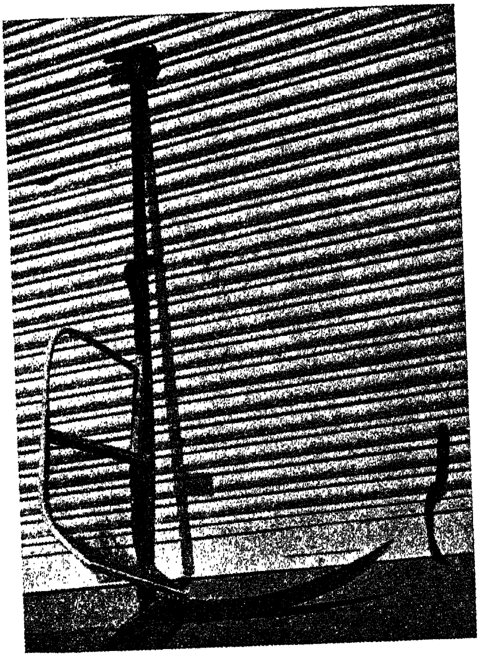


PLATE 101. Austrian scythe (Left) and toothed sickle (Right)

tackled, local climatic factors, etc. A recent survey of indigenous agricultural implements has shown that the life of the country plough varies from one to eight years. The cost of the plough varies from Rs. 5 to 25, depending upon the design, construction and cost of materials used. The iron share or cutting point usually requires to be replaced twice a year, while the wooden body may last a season. The average output with an indigenous plough is about one acre in a day of eight hours.

First ploughing results in the soil being left in a very cloddy condition; it is left in this condition during summer. The operation requires a pair of animals. In the Bombay and Deccan area, the summer ploughing operation is carried out to greater depths using a very heavy plough with two to five pairs of animals. The ground is broken to a depth of eight to ten inches or more during this operation. These heavy ploughs are now almost entirely replaced by the turnwrest type iron ploughs. It is worth noting here that many improved implements of the West were designed for multiple-team-draft and could be easily introduced into this country if methods of hitching and managing multiple teams are experimented upon and evolved. Farmers in most of the regions in India cannot manage more than a pair which places rather a severe limitation on the scope for adoption of improved implements under Indian conditions, as many improved implements have a heavy draft. It is interesting to recall that in ancient India use of multiple teams for agricultural operations was not only practised but much advocated. The following extract, from Parasara's *Krishi Sangraha*, is of interest: " Cultivation by eight oxen to a plough is a virtuous affair; it is only traders who yoke six oxen; those who are cruel employ four; and those who use only two are animal killers (butchers) ".

The object of summer ploughing is to promote aeration and microbiological activity, particularly in the clayey soils prevalent in some of the areas, as well as for conservation of rainfall and checking erosion of soil particularly during the first rush of rain water from the monsoon. Incidentally, weeds and hibernating pests are also killed or inhibited. Considering also that considerable acreage of wheat is dependent on natural irrigation from rain, summer ploughing is considered to be a very important and essential operation.

SEED-BED PREPARATION

The preparation of the seed-bed for wheat sowing begins after the monsoon, starting usually from the month of September. The sowing season is usually considered to be from the beginning of October to the middle of November for the wheats of the North which form the bulk of the wheat grown in this country. However, late sowings extend as far as the middle of December. The sowing season is earlier in the South and is progressively later as one moves to more northerly latitudes. A fine granular tilth is generally preferred in the seed-bed for sowing wheat. The technique used in the preparation of the seed-bed varies with the type of soil. In loamy and alluvial soils, the land is ploughed repeatedly with the country plough. While 8 to 10 ploughings are quite common, as many as 20 ploughings are resorted to in some localities. After the tilth is refined sufficiently by repeated working with the indigenous plough the surface is levelled and packed by dragging a wooden log or leveller or a very heavy roller. The object of this operation is to compact the seed-bed and bring the moisture line as close to the dry surface of the ground as possible.

During the course of survey of indigenous agricultural implements various types of clod crushers, levelling planks and rollers have come to light; the typical ones used in connection with land preparation for wheat are described below.

1. **Levelling plank, '*Sohaga*' or '*Patela*'.** There are different types of levelling planks used in the country. They are made of rectangular blocks of wood, the common sizes ranging from six to nine feet in length, ten inches to twelve inches wide and five to six inches thick. They may be a single-piece construction or a two-piece construction joined together by cross bars running through the width. The multiple-piece construction is considered to be more effective and superior in operation. In some cases the hind-piece is lined at its frontal side with a steel plate so as to make it more effective in clod crushing. The acreage covered per day by the levelling plank varies from four to eight acres depending on the width of sweep of the planks. The cost of operation per acre varies from Re. 1 to Rs. 1·62. The cost price of the plank varies from Rs. 10 to 20.

2. **Roller.** Where clods are difficult to pulverize, the roller does a fairly good job of clod crushing. Wooden and stone rollers are quite common in some parts of the country, as for instance in the South and the Punjab, where a heavy wooden roller is used to compact the seed-bed and to bring the moisture line as close to the ground surface as possible. This is considered very important as there is not sufficient rainfall or irrigation water supply in many regions. The area covered by the roller varies from two to four acres per day. The cost of operation per acre varies from Rs. 1·62 to Rs. 3·25 per acre. The cost price of rollers varies from Rs. 35·00 to 56·00 depending upon the construction.

3. ***Bakhar.*** In clayey areas, the preparation of seed-bed is accomplished by a blade harrow popularly known as the *bakhar* or *guntaka*. This consists of a horizontally mounted sharpened steel blade about 20 inches long. It is drawn by bullocks and worked at a shallow depth of two to four inches.

This implement not only has much greater coverage and speed of working compared with the indigenous plough, but also efficiently eradicates weeds (other than the deep-rooted grasses); it is widely used in central India and the South. It is finding favour recently in some parts of the Punjab. The main reason for its adoption in the central India and the South is perhaps that the clayey soils after preliminary ploughing form large clods, which on drying bake hard very quickly and are not pulverized by repeated working with the plough. The blade harrow has a shaving action which results in a finer and fairly uniform granular tilth. This is an implement of considerable merit for dry-farming areas.

SOWING

A well-prepared and compacted seed-bed is considered essential for sowing of wheat. The seed rate varies from 100 lb. in the southern zone to as little as 40 lb. in some parts of the Punjab. Three indigenous methods of wheat sowing are practised in different regions:

(i) BROADCASTING: This method is not practised very much for wheat except to a very limited extent. But, where this method is practised, the seed is broadcast on the land when it is in proper moisture condition and is then covered by giving one or two shallow ploughings with the country plough or by working over once with a peg-tooth harrow. The main drawbacks of this method are uneven distribution of seed and the irregular depth of placement of seed. This method, however, has the advantage of speed and is adopted when sowing is delayed for some reason or the other. Other methods of sowing are generally preferred for wheat.

(ii) '*KERA*' METHOD: This method is most commonly used for wheat sowing in irrigated areas. A woman or a boy drops seed in the furrow following the plough. The ensuing furrow in the course of being opened throws some earth on the seed thus covering it. The levelling plank is run at the end of the operation across the direction of furrows thus covering the seed to a depth of three inches or so.

(iii) '*PORA*' METHOD: Sowing in this method is accomplished by a seed spout attachment or *pora* attachment to the country plough, which consists of a funnel and a seed tube attached to the plough bottom at a distance of two-thirds the length of the bottom from the share tip. The seed is manually dropped into the funnel by the ploughman as the plough is advanced forward and gets covered partly by the soil as the implement advances. No special seed-covering operation such as planking is required. The depth of sowing can be adjusted by changing the position of the seed tube. This method of sowing is preferred more in dry-farming or *barani* areas.

There are also systems of sowing known as *haveli* in some parts of Madhya Pradesh. The water is collected by making bunds, and the strips formed as water line recedes are sown as they come in condition. In case of the *haveli* system the water is let off as the monsoon period ends, say about a fortnight before sowing. No presowing cultivation is done and the seed is sown at a depth of three to four inches with the *nari* plough which is very similar to the *pora* plough.

INTERCULTIVATION

Interculture operations are carried out by a harrow-bladed hoe similar to a miniature *bakhar* with a four-inch blade. In some parts of Bombay and Hyderabad (Deccan), intercultivation is done with a slit hoe (called *meesala guntaka* in Andhra Pradesh). There are a number of multiple-bladed indigenous hoes and split-blade harrows for intertillage between rows of growing crops. The main object of interculture is elimination of competition from weeds. Incidentally soil aeration and breaking up of surface crust is also secured. In many regions, however, not much intercultivation is done after the sowing, though in some of the northern areas particularly, wheat is hand-hoed to remove weeds, etc.

In some parts of the Punjab, a form of peg-tooth harrow called the bar harrow is used in cases where rain has fallen immediately after sowing, in order to break the soil crust. Light harrowing has been found to be quite useful when the wheat crop is young, as it not only helps in checking weeds and reducing white-ant damage but is also thought to help in conservation of soil moisture thus delaying the application or the first watering after sowing.

Secondary preparatory tillage operations. After mould-board ploughing, the land is worked by a harrow, of which there are two principal types—the toothed or tyned harrow and the disc harrow. This secondary operation pulverizes the soil clods, cuts up trash and vegetation, clears the land of trash and compacts the seedbed. There are many types of animal-drawn harrows manufactured in this country, the most common being the peg-tooth harrow or bar harrow consisting of steel spikes driven through a triangular wooden frame. The all-steel harrow with adjustable points, the steel spring-tyned harrow and the lever-expansion harrow permitting variable width of cut are also available. The hitching and adjustment of these implements present no particular problem and hence do not call for any extraordinary skill. After harrowing it is usual to smooth and compact the seed-bed by a plank or a roller (called *patela* or *pata*). An interesting harrow is the combined harrow and plank called the ' Singh Patela ', which consists of a plank with several curved tynes fitted to one edge. This arrangement enables the device to be used as a harrow or as a plain plank for smoothing.

Land levelling and smoothing. It is important in irrigated culture that land be made as level as possible. The operation consists of accurate determination of levels with the surveyor's or engineer's level and marking out the high and low spots. After this, the earth is moved from high spots to the low spots with a bullock-drawn buck scraper, locally called *suparah.* Ploughing and harrowing the land greatly facilitates this levelling operation. After the variations in level are brought within a few inches of a pre-determined average grade, a device known as a float or land plane is used to bring the land to perfect grade level. This operation is known as land grading for irrigation and is in the nature of permanent improvement. This practice is coming into vogue increasingly in the United States of America and is worthy of consideration in India. A typical cost of operation in U.S.A. may run to as much as $ 80 to $ 100 per acre, which shows the importance attached to this operation.

The operation of cutting high spots and filling low spots need not be repeated every year and the grade level can be maintained by using the float or land plane every year as a finishing operation for seed-bed preparation.

Sowing is a key operation and is best done with automatic seed drills. Animal-drawn models sowing up to seven lines simultaneously have been designed and successfully used. Sowing by drills has several advantages, in addition to the saving in time and labour. Better use also is made of the available soil moisture. One man and a pair of bullocks can easily sow about three to five acres per day. Another major advantage is that the crop is sown in lines making it easier to undertake the post-sowing intercultural operations. Some of the common types of the bullock-drawn seed drills used in the northern parts of the country are the *rabi* drill and the automatic *rabi* drill. Some seed drills are equipped with fertilizer placement devices which not only effect a great saving of fertilizer but also place it at the most favourable depth.

Many modern designs of seed drill incorporate a fertilizer placement attachment so that fertilizer can be placed along with seed as it is being sown. Accurate control of seed and fertilizer rate as well as the depth of sowing and placement is possible. A wide variety of furrow openers are available to deal with the wide range of conditions met with in practice. Next to the harvesting machinery, fertilizer-cum-grain drills are the most expensive farm equipment. During sowing time speed is of essence so that proper germination and crop stand is obtained and established. Delay in sowing has an adverse effect on the ultimate yield. It has been demonstrated beyond doubt that under North Indian conditions any delay beyond the 15th November could result in considerably reduced yields. Similarly, depth of seed placement also affects emergence to a remarkable extent. It is said that proper germination and crop stand is winning half the battle in crop production. It is, therefore, easy to see why there is

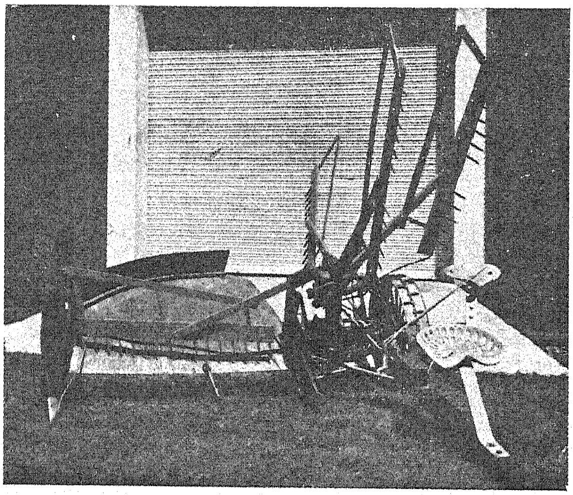


Plate 102. Animal-drawn reaper for harvesting and windrowing standing crop; can be operated by two men and two pairs of bullocks.

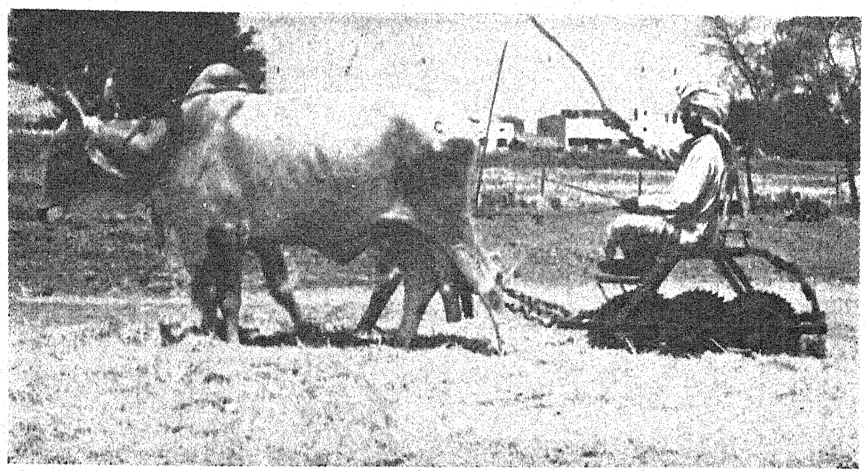


Plate 103. Threshing with Olpad thresher

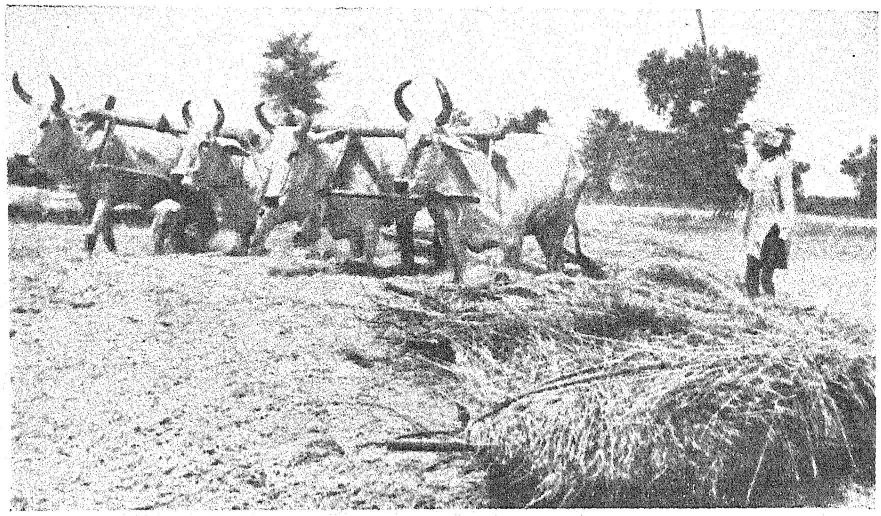


PLATE 104. Threshing with *palla*

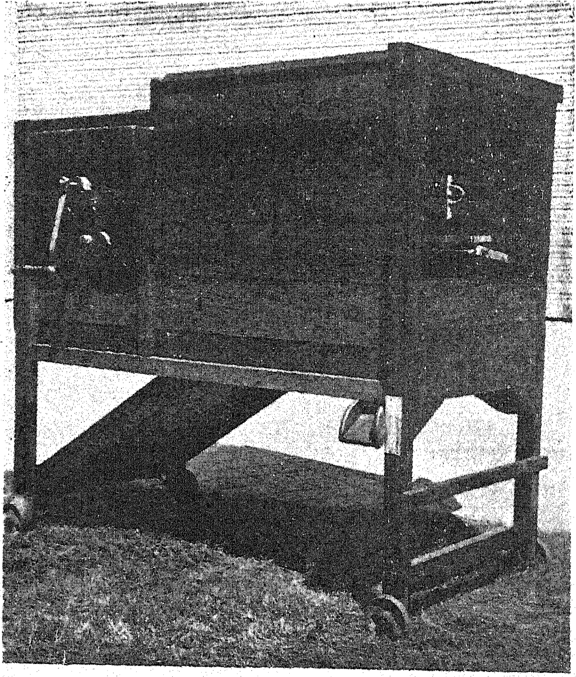


PLATE 105. Winnowing machine—this is operated by three men

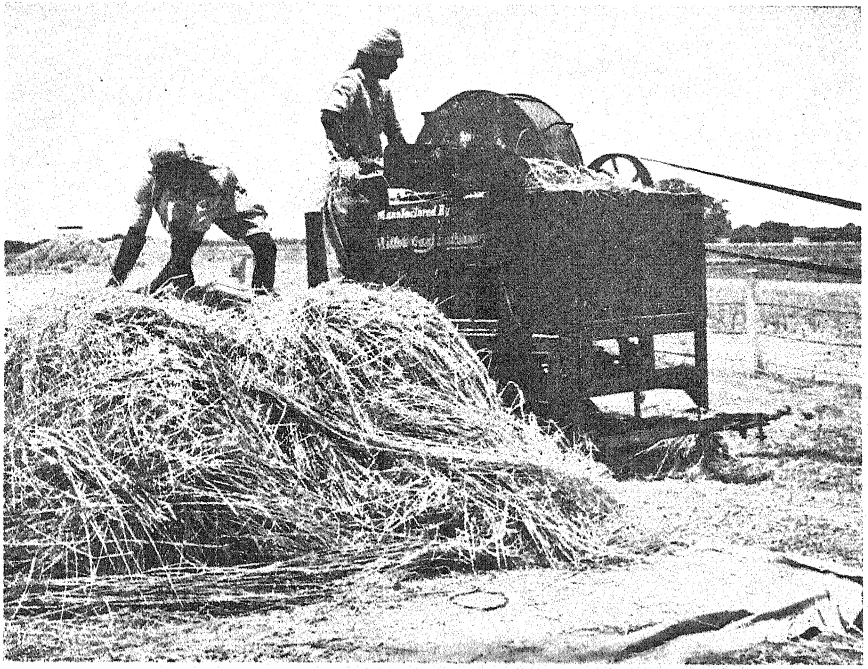


PLATE 106. Ludhiana thresher

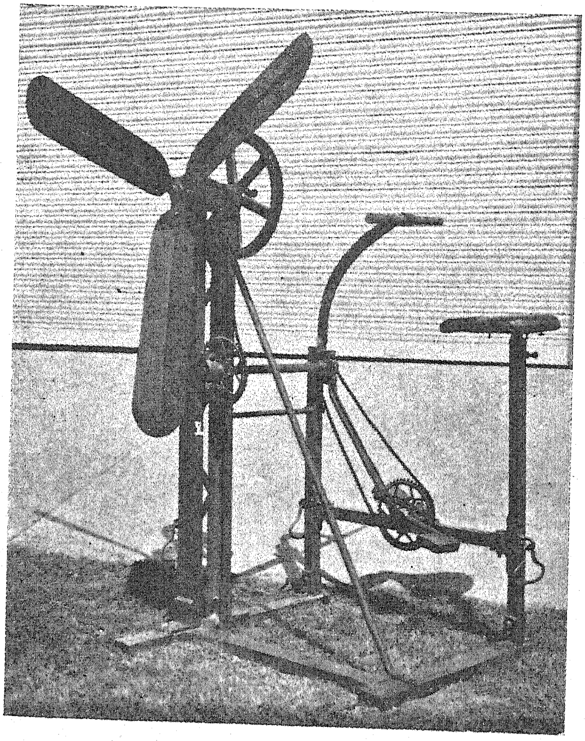


PLATE 107. Fan for creation of breeze for winnowing—this can be operated by one man

a great demand for improved precision type seed drills and why good machines which are necessarily expensive are being preferred by progressive farmers. Yet at the same time there is scope for designing simpler, inexpensive types for small farmers with limited financial resources.

HARVESTING AND THRESHING

Harvesting. The harvesting of wheat is carried out when the crop is ripe. Care is always taken to avoid over-ripening of the crop in order to avoid shedding of grain. Most of the harvesting of wheat done in India is through manual labour and hand tools. However, bullock-drawn reapers are used to a limited extent and are at the moment mostly confined to government farms. Private individuals are also showing greater interest mainly on account of the great saving of labour which is particularly scarce and expensive during harvest period.

(i) *Hand tools :* Manual harvesting of wheat is usually done with a sickle having a serrated cutting edge, although the plain sickle is also used in some places. The stalks are cut as close to the ground as possible so as to recover the maximum quantity of straw for *bhusa.* The sickle is used by labourers in a squatting position. It may be stated that the demand for labour increases considerably during the harvest period and sometimes it becomes very difficult to obtain sufficient labour for harvesting purposes. But, due to the small size of plots prevalent in most areas harvesting has to be done with the sickle. A man with a sickle can harvest about ¼ acre per day and the average life of the implement is considered to be about three to four years. Due to the slow rate of work possible with the sickle and the acute shortage of labour experienced during the harvesting season, it is desirable that labour-saving devices are evolved for harvesting.

The scythe used in some western countries is more than a good substitute for the sickle having an output of more than an acre per day of eight hours. But its action is more severe on the crop and the harvesting has to be done with it as soon as the crop approaches the full ripening stage. The cutting blade of the scythe is about three and a half feet and it can easily cut a swathe of about four feet when used by a trained hand. The wielding of the scythe demands some skill and a labourer in the West can usually harvest one to one and a half acres of wheat per day with it. The men who follow the scythe-man collect the cut wheat and tie it into bundles. The possibility of introduction of this scythe into India has been under examination and some preliminary experiments have been conducted.

Recently some Austrian scythes have been imported and trials and demonstrations are in progress at the Indian Agricultural Research Institute and in the various states of India for their suitability and introduction under Indian conditions.

(ii) *Bullock-drawn reapers:* Several types of bullock-drawn reapers have been imported in the past and tried in this country and an effort has been made to introduce them. Due to the high capital cost of the machines, however, they have not become very popular so far. Small size of plots has also militated against their use in the past.

(iii) *Reaper binders :* Self-binding type of reapers, called reaper binders, have also been tried in the country, but because of their heavy draft they have not become very popular. Their use also required larger plots and they are mechanically much more complicated than a plain mower. Their size and bulk also makes it more difficult for them to negotiate field bunds. But, the machines have been considerably improved, and the present conditions of chronic labour scarcity during harvesting season makes the possibility of their reintroduction worthwhile considering.

Threshing. Most of wheat threshing in India is done through the use of bullock and manual labour. This requires the use of a good threshing floor. The threshing floor consists of a small piece of land thoroughly cleaned of all the shrubbery and compacted and dung paved to lay off dirt and dust. A brick-paved threshing floor is a worthwhile investment in a farm. The plot is selected on a firm ground and sometimes it is plastered with mud also. The wheat stacks are spread over the floor and trampled by bullocks which are made to walk round and round on the crop. Following are the various indigenous methods.

(i) '*MEHAR*' SYSTEM : In this system only bullocks tread over the threshing floor and there is no implement hitched to them. The number of bullocks used depends on the size of the threshing floor and the quantity of wheat to be threshed; thus the number of bullocks used may vary from 4 to 16. The major disadvantage of this system is that it is very slow and laborious.

(ii) '*PALLA*' SYSTEM : This method of threshing is used mostly in the northern parts of this country. The wheat stacks are spread over the threshing floor and threshing is accomplished through the use of the '*palla*', which is dragged by a pair of bullocks on the threshing floor. The *palla* has a rectangular frame made up of cotton sticks or *shisham* branches. The wheat is constantly stirred by a fork while the bullocks dragging the *palla* tread over it in a circular path; this lets the grains pass to the floor bottom. The same effect can be achieved by the use of a peg-tooth or bar-toothed harrow. Wheat crop of one acre (15 md.) can be threshed in a day of eight hours by this method.

(iii) OLPAD THRESHER : The Olpad thresher has gained great popularity for threshing of wheat and gram. The origin of the term Olpad is somewhat obscure. This thresher is also mentioned in a survey of indigenous agricultural implements of Bombay State by Kelkar—published by the Department of Agriculture, Bombay, as early as 1914—which shows that it is not of recent origin. The implement somewhat resembles a tandem disc harrow having flat serrated disc without any concavity.

Winnowing and winnowers. (i) The indigenous method of winnowing consists of throwing up in the air the threshed matter when a light breeze is blowing. This results in blowing away of the light chaff leaving grain mixed with *bhusa*, that is, finely chopped straw. This is then winnowed by letting the crop dribble in a slow stream from a *chhaj* or a winnowing basket in a light breeze, which plays a major part in this process. This method is, however, slow and laborious. In case of rain during the threshing or winnowing period the grain as well as *bhusa* is liable to get spoiled and hence instead of uncertain natural breeze more efficient and dependable devices are preferred for this purpose.

(ii) WINNOWING FANS : Various types of pedal and fan type treadle and hand-operated winnowing fans have been developed in this country. They produce a steady breeze to help the labourers armed with a basket, who can each winnow about 10 to 12 md. of grain per day depending on its size, construction, etc.

(iii) WINNOWING MACHINES : These consist of a fan blower with a handle. The chaff mixed with grain is loaded into a hopper from which the stuff is fed to a number of sieves, which oscillate and vibrate as the crank handle is turned. The sieves shake off the dust and foreign matter which is blown away by the current of air created by the blower. The grain is retained by the lower sieve and is delivered to one side; these machines enable winnowing to be done more speedily and with less labour. By proper selection of the sieves it is possible to obtain graded seed. The value of seed grading needs to be appreciated more than it is at present.

XVII

MARKETING

A great deal of detailed information on marketing and allied aspects is contained in an admirable report on the marketing of wheat in India, published some years ago (Anon., 1937, 1946). A short account of some of the salient features is given below.

Production. As a result of the partition of the country in 1947, India lost nearly 11 million acres of rich wheat-growing areas to Pakistan with a consequent decline of nearly four million tons in her average annual production of this crop. As compared with pre-partition figures, the acreage and annual production of wheat declined by 31 and 39 per cent respectively. It is, therefore, ample proof of the economic importance of this crop and a testimony to the technological possibilities of agriculture in this country that, within the short space of only ten years, the area under wheat has expanded by five million acres and the average annual production has gone up by slightly more than two million tons (Fig. 18). The average yield per acre under this crop has almost caught up with the pre-1947 picture. The average annual production during 1957–58 was 9·06 million tons, valued roughly at Rs. 400 crores.

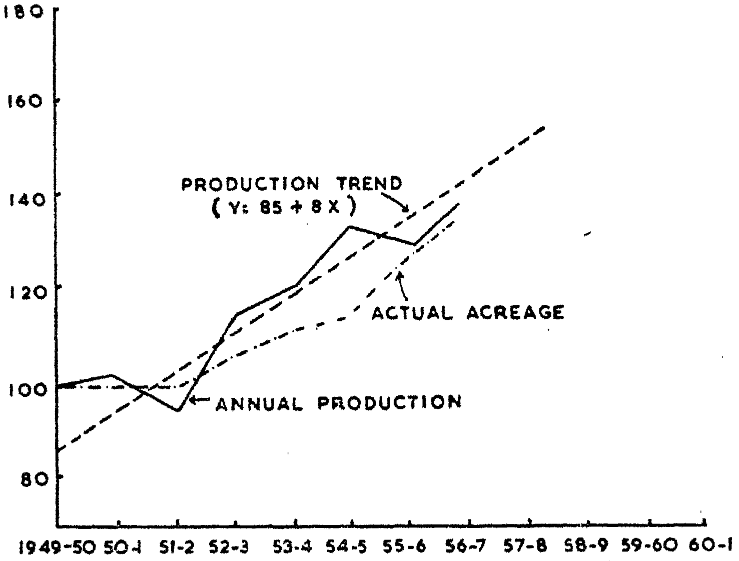


FIG. 18. Trends of wheat production and acreage in India (1949-50=100)

India's share in the world production of wheat was estimated to be roughly 9 per cent at the beginning of the century. It registered a steady decline to about

7 per cent of the world crop at the time of partition. This trend has continued in the years following partition. Without taking production in the U.S.S.R. into account, India produced 4·3 per cent of the world crop of wheat during 1948–52 and 4·1 per cent during 1958. The principal reason for this decline lies in the increasing production in the great exporting countries such as the U.S.A., Canada, Argentina and Australia, and also in more recent years in China. The average yield per acre in these countries is 1·5 to 1·8 times higher than the Indian average.

Within the Indian Union, the major wheat-producing states are U.P., Punjab, M.P., Rajasthan, Maharashtra, Gujarat and Bihar (Fig. 19). These states account for 94 per cent of the acreage and 96 per cent of the production of wheat in the country (*see also* Table II on page 8).

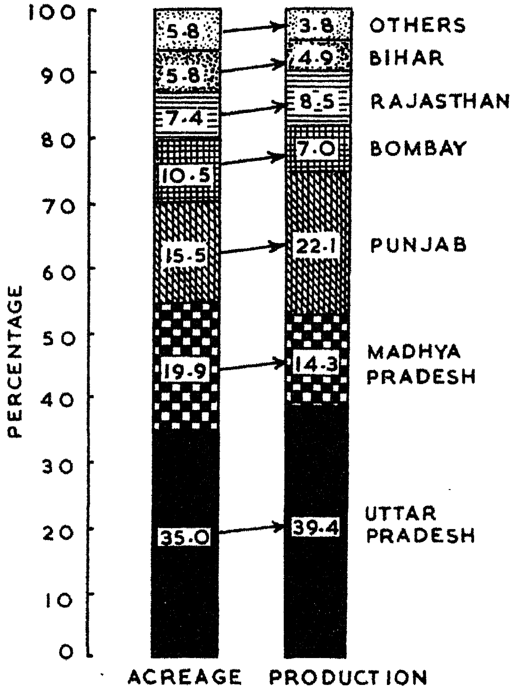


FIG. 19. Share of major producing states in acreage and production of wheat

Imports. Imports into India fell considerably after the levy of 'non-protective' special duty in 1931. With the lowering of duty in 1935 and again in 1936 and the parity of Indian and the U.K. wheat prices, imports rose during 1937–39. During 1939–47, abnormal conditions created by the war disrupted this pattern. Imports have risen again during recent years as a result of the decision of the Government of India to build up buffer stocks and to put a check on speculative elements in the wheat trade within the country. The agreement concluded with the U.S. Government recently ensures the flow of 16 million tons of wheat into India during the next five years. These shipments will be made under the generous terms of P.L. 480 and would greatly help in maintaining the price line as regards wheat.

Exports. Owing to their water-absorbing capacity, their suitability for blending and the comparatively lower prices at which they were sold, Indian wheats had a ready market in Europe and more particularly the U.K. since the opening of the Suez Canal. In the last two and a half decades, however, high internal prices and severe competition from the large shippers appreciably reduced the exports. Export markets were practically lost to India from 1935, and the insufficiency of internal production to meet the growing demands of an increasing population have virtually made exports impossible.

Commercial description and distribution. Botanically, the important wheat varieties grown in this country mostly belong to *T. aestivum* although a small proportion belongs to the species *T. durum*. Yet another group, *T. dicoccum*, constitutes a very negligible fraction of the crop and is confined to the Deccan region. Commercially the crop is described mainly by grain texture (hard or soft) and testa colour (white or red). The commercial names of the principal varieties and their distribution are indicated in Table LXXIX.

TABLE LXXIX. COMMERCIAL VARIETIES OF INDIAN WHEAT

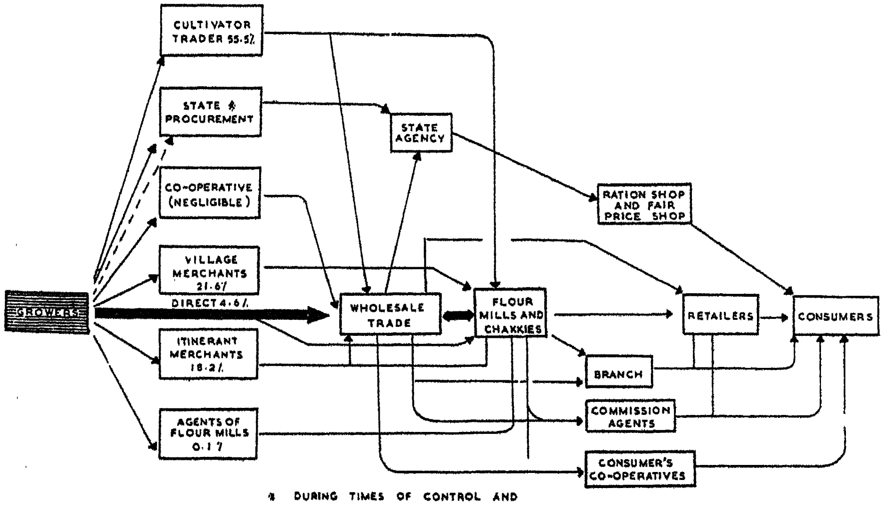
Botanical classification	Majority group		*Triticum aestivum*
	Minority group		*T. durum*
			T. dicoccum (negligible fraction)
Physical classification	*Colour*	*Texture*	*Varieties*
	White	Hard	*Dara* or *sharbati* type of N. India (*T. aestivum*)
			Bansi, *Jalalia* and *Khandwa* varieties of Bombay (*T. durum*)
			Khapli of Mysore and Bombay (*T. dicoccum*)
		Soft	*Dara* or *pissi* types of M.P. and southern parts of U.P. (*T. aestivum*)
	Red	Hard	*Lal kanck* of the Punjab and Delhi (*T. aestivum*)
			Kathia of Rajasthan and M.P.
		Soft	*Lal pissi* of M.P. (*T. aestivum*)

The white wheats command a general premium over the red ones. The soft *pissi* types always fetch lower prices than the hard *sharbati* types. The *durums*, invariably hard, command the highest prices of all commercial types.

Per capita consumption. For the entire country, the per capita consumption per annum of wheat and wheat products varies between four and five pounds in the non-wheat-growing areas and nearly 300 pounds in the larger cities of the North.

Estimates of marketable surplus. It is difficult to try and determine the quantity of wheat put on the market after providing for the reservations for seed purposes and for home consumption, etc., by cultivators and others, in the villages. Factors having a bearing on this subject include the extent of indebtedness of the grower, the extent of prevalence of the system of payment in kind to labour, especially during harvest, the size of cultivators' holdings, the comparative value of other food grains such as gram, barley, maize and rice that are grown locally, and finally, the food habits of the local people. All these factors are naturally subject to wide local and regional variations. We do not have any reliable studies on the extent of the marketable surplus in the crop for recent periods. Furthermore, the acreage and production figures in respect of Bihar and the bordering areas in U.P. are subject to great fluctuations from year to year as the yield of wheat in this region is affected very much by seasonal conditions. According to studies conducted in 1935–36, roughly 45 per cent of the total crop in the country was retained by the cultivators in the villages to provide for seed, domestic consumption, barter and payments in kind for hired labour, etc. Estimates made in 1944–45 also indicated that 55 per cent of the total crop was marketed. According to a report presented by the Directorate of Marketing and Inspection at a seminar sponsored jointly by the FAO and ECAFE, the marketable surplus of wheat during 1957–58 was estimated at 39·4 per cent of the crop, amounting to a little over three million tons. This finding adds weight to the belief that the food habits in our villages are changing and that a larger fraction of the wheat produced is now retained on the farms and in the villages for local consumption than before.

Share of marketable surplus assembled by various agencies. The share of the marketable surplus attributed to various agencies engaged in the marketing of wheat and the nature of the route followed by the commodity on its way to the ultimate consumer are shown in Fig. 20.



* DURING TIMES OF CONTROL AND COMPULSORY PROCUREMENT ONLY

Fig. 20. Wheat marketing channels in India

Apart from Government agencies, producers, village *baniyas*, merchants and *arhatyas* play a major role in the primary assembly of the produce. The itinerant merchants and *arhatyas* of various kinds are the major distributors.

Government as an agency engaged in distribution. The quantity of wheat procured from producers within the country and that imported from foreign countries during the period 1949 to 1956 are given in Table LXXX. The large quantities involved, viz., nearly 3·5 million tons procured and 10·5 million tons imported indicate the magnitude of government participation in the trade and distribution of this commodity.

TABLE LXXX. INTERNAL PROCUREMENT AND IMPORTS INTO INDIA OF WHEAT DURING 1949–56
('000 TONS; SOURCE: *Bull. Food Statistics*, JAN., 1958, TABLE 4)

Year	Procurement	Imports
1949	557	2,150
1950	1,115	1,412
1951	787	2,966
1952	780	2,170
1953	209	1,342
1954	—	121
1955	—	56
1956	—	275
Total	3,448	10.492

Since 1953, when the position of food supply was considered to have reached a satisfactory level, internal procurement was relaxed although it has never been completely stopped.

Share of distributing agencies in the consumer's rupee. No nation-wide study has been made in recent years on the costs of assembling and distribution and price spreads between producer and consumer in the case of wheat. The Federation of Indian Chamber of Commerce and Industries made an effort to interpret the original studies conducted by the Central and State Agricultural Marketing Directorates. There is good reason to believe that the growers' share has been increasing gradually in recent years.

Market charges. Since precise quantitative assessments are extremely difficult and there cannot be anything like a representative all-India picture, Fig. 21 gives at best a rough idea of the sharing of the consumer's rupee in the ultimate retail market. The welter of charges to which the grower carrying his produce to the Primary Assembling Market is subject to is quite confusing. He has to satisfy the municipal employees at the octroi post, the *kutcha arhatya* and his tout the *dalal*, the *rola* who dresses his wheat, the *tola* or weighman, the *palledars* or market labourers, the *munim* (*arhatya's* clerk), the watchman, the *bhisti* (waterman), the sweeper and a number of others who demand a share of his produce. Rather than face such multiple demands and the inconveniences of going to the distant market, he prefers to sell on the spot to the local *baniya* or the itinerant buyers who come to his village.

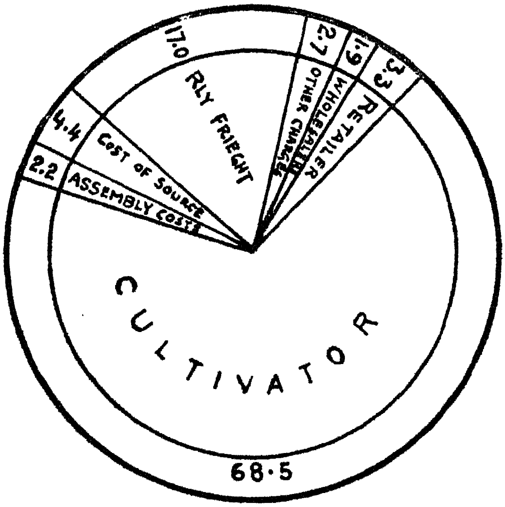


FIG. 21. Sharing of the consumer's rupee

These marketing charges suffer from the defect that they are generally not precise. Also, several of them levied for charitable and religious purposes are either expropriated by the collecting agency or utilized in such a way that the cultivator and his family do not stand to gain in the process. By way of illustration, a few of these charges are discussed below.

The levy of an arbitrary rate of deduction which goes by various names as *karda*, *garda* or *dane* on account of impurities (refraction), regardless of their actual nature and extent, is harmful both to the grower and the trade. This arbitrary deduction existed even in the export trade where 'F.A.Q.' (fair average quality) grain supplied was held to be the basis of contract. Above the arbitrary rate, deduction for excessive refraction could be made from the contract. Under a non-mutual contract, the benefits of a lower refraction, however, would never accrue to the grower-seller, but remain as the shipper's or *arhatya's* gain. This practice has given birth to two otherwise undesirable and unnecessary practices, namely, (i) organized adulteration, and (ii) cleaning of wheat at various stages as it passes from the grower to the consumer.

Prices. Examination of the ruling prices for wheat in different markets is beset with many difficulties. Proper records are hardly kept; there is no uniformity in the market quotations; there are no uniform standards of grade and classification; the units of quotation vary from one market to another and the weights used are neither standard nor always the same for buyers and sellers.

In markets which have well-organized trade associations, prices for similar types and kinds of wheat move more or less in harmony with one another and the differentials depend on the distances of the markets from the producing areas. Where no such associations exist, there are considerable aberrations in price movements. All this increases the risks of marketing and is reflected in the extra costs of distribution. A firmer link amongst different important markets is an obvious need.

Like all agricultural products, prices of wheat and wheat products in a 'free' market show considerable seasonal fluctuations. These fluctuations offer a serious threat to the grower. Prices are depressed between January or February and August, with the depression reaching its peak level either in April or May. When one considers this with the knowledge that about 40 per cent of the total home-grown supply is marketed soon after harvest from the beginning of April until June or mid-July, the disastrous effects of this situation on the finances of the producer can be readily imagined. Prices, which start pulling up by June-July again manifest a general drop between August and September as the condition of village roads improves with the cessation of the monsoon, thereby making it possible for the grain to move towards the market. Prices thereafter register an autumnal or mid-winter rise between October and December or January. With the heavy shipments of wheat from abroad in recent years and the introduction of fair-price shops in urban areas, where rates of wheat and *atta* are controlled by the Government, the free market situation has ceased to exist. What actually prevails is a stabilized market in which both movement and prices are conditioned by decisions of the Government. Prior to the stoppage of 'futures' business by the Government, the September price dip used to be much more pronounced owing to the release on the market of futures by trading associations of stocks hedged in the September position. While a stabilized market in which the Government plays a dominant and decisive role tends to remove precipitous rise or decline in prices, these trends are still apparent as can be seen from Fig. 22.

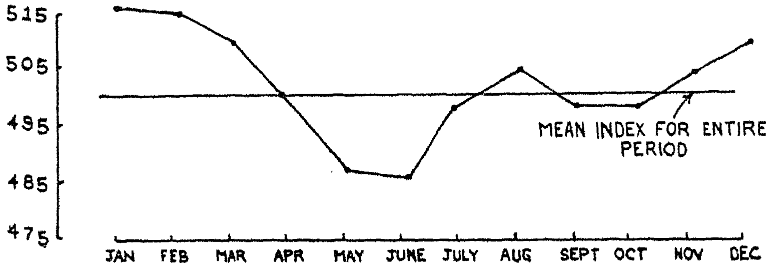


FIG. 22. Average monthly indices of wholesale price of wheat, 1949-50—1956-57 (1939=100).

With the buffer stocks built up by procurement and imports, efforts are made to correct maladjustments between supply and demand for food over short periods. During 1957 when the country experienced food shortage due to failure of *rabi* crops over large areas of eastern U.P. and Bihar, 2·16 million tons of wheat were released, the bulk of it being sold through the 38,000 fair-price shops established in important cities all over the country. The Government has also experimented with the idea of guaranteeing minimum prices at strategic terminal points of the distributive channel during periods of declining prices with the purpose of cushioning up prices of food grains, thereby correcting the imbalance between agricultural and non-agricultural prices and affording some relief to producers in areas hard hit by price declines. With wheat, this policy was tried between March and July 1955 when the Government was prepared to buy and actually purchased nearly 76,500 tons of 'F.A.Q.' wheat at rail-head *mandies* at Rs. 10·00 per md. as prices fell below this level. Purchases under this 'limited price scheme' were not found necessary after 1955. With such a short experience of this scheme, therefore, it is not possible to come to any firm conclusion about its working.

Grades. The question of prices naturally leads us to that of grades and classification. In addition to colour and texture, other items of importance from the consumers' point of view are: (a) dryness, hardness and strength of grain, (b) size of grains, (c) admixture with other grains, (d) admixture with dirt, and (e) infestation by insect pests and diseases. These give us an adequate basis for establishing grades. Price differences due to quality are mainly based on the presence of preferred factors or absence of unwanted characteristics. Unless all these factors are given a clear recognition by buyers as a whole, it will not be possible for better-quality produce to obtain the necessary premium over inferior grades. As was mentioned earlier, there is an unfortunate general tendency for low-quality grain to drag down the prices of better-quality produce with a consequent loss to the grower. In the case of 'futures' contracts also, considerable variations have been noticed in the quality of wheat tenderable under contracts of many exchanges. This was particularly true for contracts providing for high refraction allowances on a non-mutual basis. As a result of all these variables, traders of one market experience considerable difficulty in dealing with a different market. Efforts are being made and some progress has been achieved in the establishment of standard grade classifications which could serve as an accepted basis for all trade transactions.

Storage. The customary methods of storage of wheat are conservation in bamboo *thekkas* or bags when dealing with small quantities or bulk storage underground and bulk and bag storage in *kothas* or godowns. Since the Government has taken up bulk purchases and distribution, properly lined and insulated, insect and vermin-proof storages are being constructed in many important centres for assembling and distribution of food grains. The mechanized ten thousand-ton iron silo-cum-elevator storage constructed at Hapur is a case in point. Over 30 such storages are being constructed in different parts of the country.

The cost of storage in bags is prohibitive and in general the losses too are heavy in such storage. Although bulk storage in *kothas* is ostensibly less costly than storage in bags, there is hardly any merit to recommend in this system unless the storage is for very short periods. Over the years as costs, in general, have tended to rise, the relative increase in rental charges and handling costs has been greater in the case of *kothas* than with pit storage. Losses due to the attack of vermin and insect pests and deterioration in quality of stored grain are quite considerable with storage in *kothas*. From all these points of view underground storage is the most economical. For this to be so, however, the storage must involve a reasonable minimum period of six to eight months. In areas of low rainfall, where rise in the subsoil water level does not pose a serious problem, *kutcha* pits afford a very economical means of storage. Where the question of maintaining quality of grain assumes importance, concrete pits may be recommended for bulk conservation. Studies in storage costs during 1943–44 (Anon., 1946) revealed that, inspite of the increased costs of storage since 1935–36, the entry of the Government into the business of purchase, storage and distribution of wheat on an extensive scale had led to a reduction in the margins accruing to the storing agencies. The profits on storage at Chandausi in U. P. were reported to have come down by 2·7 per cent for *kothas* and 5 per cent for *khattis*.

Storage being a specialized function, both on account of physical handling of the grain as well as the serious seasonal fluctuations in price to which wheat is subject, cannot be undertaken by the average individual grower who lacks the necessary facilities and resources including finance and up-to-date knowledge of market conditions. The immense advantages of cooperative marketing by growers will be obvious in this context.

Regulations of markets and cooperative marketing. *Ad hoc* studies conducted at different places indicate the following trends :

(i) Growers are now getting a more effective say in the timing and volume of sales. They are now in a stronger position to withhold their produce when ruling prices are adverse to their interests.

(ii) There is strong evidence of a gradual increase in the growers' share of the assembling of wheat. This share has been estimated at 55 per cent for the country as a whole, the corresponding estimate for the Punjab standing at 73 per cent. Areas where regulated markets have been established by law and where these markets have taken hold are the ones where the latter trend is most clearly manifest.

(iii) In regard to cooperative marketing, all that can be said at the moment is, that while considerable hope is placed in the system, it has yet to be seriously tried. It was recently estimated that a bare 1 per cent of the wheat placed on the markets in the Punjab was sold through cooperative societies.

Wheat products. The wheat products of commercial value in India are wheat flour (*atta*), semolina, *suji* and wheat bran (*chokar*). Leaving apart the quantity of wheat annually reserved for seed, about half of the remaining three million tons retained in villages is crushed in hand-*chakkis*. It has been estimated that about four million tons are converted into *atta* in small-power rollers, of which the numbers have steadily risen over the years. Only a small fraction of this quantity is left as bran after sieving for domestic use. The bulk of this bran is locally used as cattle feed. Another three to four lakh tons of bran produced from the roller mills enter the commercial channels for sale as stock-feed. The bulk of about eight lakh tons of *maida* and 1·5 lakh tons of *suji* estimated to be produced from the roller mills is also put on the market. The use of wheat flour for the biscuit-making industry is steadily increasing in the country. By present estimates, 17,000 tons of biscuits are produced annually, requiring approximately 6,800 tons of wheat. As regards prices, it may be observed that, on the whole, the prices of wheat products seem to be fairly closely related to the cost of the raw material.

Recommendations for improvement of marketing. From this brief review of the various aspects of marketing of wheat, it will be obvious that there exists a vast scope for effecting improvements in the marketing of wheat in the country. Some steps which may be worthy of consideration in this connection are listed below.

1. Mandatory establishment of standard grades and similar use of standard weights and quotations.
2. Regulation of markets and market practices.
3. Improvement of storage facilities in villages and *mandies*.
4. Improvement of transport and communication, including better use of village radio service for prompt dissemination of market information.
5. Active encouragement of the organization of cooperative warehousing and marketing corporations.

6. Intensive research on market conditions with a view to obtaining data which would enable the State Governments to formulate their policies on a rational basis.

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ADDENDUM

INTRODUCTION OF THE NORIN DWARFING GENES IN WHEAT BREEDING

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Fertilizer response is more a morphological than a physiological problem and unless the plant has a morphological frame which enables it to resist lodging, the application of fertilizers and water in the quantities required for high yields is not possible. If the variety is not tailored to the needs of high fertility conditions, the yield may even tend to get depressed with the application of nitrogen doses exceeding about 40 kg. N per hectare. A short, non-lodging habit is hence a pre-requisite for introducing a new agronomy capable of enhancing yields. Several dwarfing genes were known for a long time in wheat, such as the S or C loci, which govern the *sphaerococcum* and *compactum* characteristics respectively. These loci, however, all had a pleiotropic effect on the ear, making it very dense and compact. The first variety which appeared to have the desired combination of short plant height, lodging resistance and kernel type was Norin 10 (Vogel, C. A., Craddock, J. C., Muir, C. E., Everson, E. H. and Rohde, C. R. 1956. *Agron. J.* **48:** 76-78). This variety was one of a collection of Japanese wheats brought to the United States by Dr. S. C. Salmon in 1948.

Using the Norin dwarfing genes, the dwarf winter wheat variety, Gaines, was developed by Dr. Vogel in the Washington State, United States. Spring wheat varieties had been developed in Mexico by Dr. N. E. Borlaug, using the Norin genes for dwarfing (three independent genes have so far been found).

In order to develop dwarf wheat varieties suitable for cultivation in India, the Indian Agricultural Research Institute, New Delhi, introduced in 1963 a large variety of wheat material containing the Norin dwarfing genes from Mexico through the courtesy of the Rockefeller Foundation and the Mexican Ministry of Agriculture (Swaminathan, M. S. 1965. *I.A.R.I., P.G. School J.* **3 :** 57-62). In addition to breeding material, bulk quantities of four commercial spring wheat varieties—Lerma Rojo 64A, Sonora 63, Sonora 64 and Mayo 64—were also obtained. These varieties were tested in all the wheat-growing states of India during the *rabi* seasons of 1963–64 and 1964–65 under the All-India Wheat Improvement Project. Besides, they have been subjected to detailed physiological, pathological, chemical and agronomic tests at the Indian Agricultural Research Institute. Two of these varieties, Lerma Rojo 64A and Sonora 64, were approved by the Central Variety Release Committee of the Indian Council of Agricultural Research in 1965 for cultivation in irrigated areas.

Lerma Rojo is a late variety with a high degree of resistance to yellow rust. It performs very well under timely sown conditions and in areas characterized by yellow rust epidemics. Sonora 64, on the other hand, is an early variety and is well suited for being grown in rotations like maize—wheat, potato—wheat, rice—wheat, etc. It is the most lodging-resistant variety so far developed. Being early, it is a safe variety for cultivation under high fertility conditions in the eastern part of U.P., Bihar, West Bengal, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra and Orissa. Sonora 64 should not be sown before the middle of November in areas where the normal sowing time is late October or early November. It is susceptible to yellow rust and hence is not recommended for areas where yellow rust appears in an epidemic condition.

CHARACTERISTICS OF LERMA ROJO AND SONORA 64

Disease resistance. Resistance to individual races of rusts was studied at the Division of Mycology and Plant Pathology of the I.A.R.I. and it has been found that Sonora 64 possesses resistance to 12 races each of black and brown rusts and four races of yellow rust. It is susceptible to loose smut and hence in seed farms the seeds should be treated against smut infection. Lerma Rojo is resistant to eight races of black rust, six races of brown rust and seven races of yellow rust.

Lodging resistance. Sonora 64 has two genes for dwarfing , while Lerma Rojo has one such gene. As a consequence, Sonora 64 has a very high degree of resistance to lodging.

Growth pattern. Detailed studies of growth and development in the dwarf wheats have shown that Sonora 64 produces only six to eight tillers, all of which come to maturity synchronously. Using a seed rate of 100 kg. per hectare and four to five irrigations, yields of five to six tons per hectare have been obtained. The synchronous tillering habit enables this variety to make an effective use of the fertilizer and water applied.

Biochemical characteristics. The protein and other quality characteristics have been studied in detail. On an average, the protein content of the grain was found, during 1964-65, to be 14·6 per cent. While Lerma Rojo is a soft wheat, Sonora 64 has strong gluten and has good *chapattee*-making qualities. When N is in abundant supply, irrigation during grain development does not lead to mottling of grains. The grains have a red colour.

Agronomic and cultural requirements. The dwarf wheats showed a very poor stand at several trials. The seeds showed 100 per cent germination in petri-dishes but the emergence of the seedlings in the fields was poor. This was due to the deep sowing of the seeds which the tall varieties tolerate, but the dwarfs do not. The dwarf strains have a short coleoptile, which is unable to penetrate a long distance if placed deep. Sonora 64 is particularly affected by the type of sowing practised by our farmers, who often sow wheat at a depth of four to six inches so as to place the seeds in the region of the soil which has adequate moisture. If a pre-sowing irrigation is given, there will be enough moisture in the upper strata of the soil and the seeds can be sown at a depth of two inches from the surface. Under such conditions, germination and tillering of Sonora 64 and Lerma Rojo are excellent. Irrigations prior to sowing and during grain development (February and March) are exceedingly important for realizing the full yield potential of these varieties. The maximum temperature during

March at Delhi ranges from 29° to 32°C and at this time usually hot dry winds occur. While the normal varieties will lodge if an irrigation is given under such conditions, the dwarfs can be safely irrigated.

Yielding ability. The yield tests conducted during 1964-65 have confirmed the expectations these varieties raised during 1963-64. Lerma Rojo, because of its higher degree of yellow rust resistance, has been found to do well in parts of the Punjab and U.P., where yellow rust is a problem. Sonora 64 does very well in all areas where yellow rust is not a problem. At Delhi and Dohad (Gujarat) a yield of 6·4 tons per hectare was obtained with this variety during 1964-65.

New selections. Varietal diversity as well as a rapid replacement of varieties are essential for sustaining high wheat yields over many seasons. From the advanced generation material sent by Dr. N. E. Borlaug in 1963, several selections such as S. 227 and S. 307 have been found to perform very well in the Northern Plains Zone. Both these strains have amber grains and a high yield potential. The highest yield in national demonstrations in 1965-66 was obtained with S. 227, which yielded 68 quintals per hectare in a farmer's field in the Punjabkhod village of Delhi State. S. 307 is a derivative of a cross involving Lerma Rojo and the Japanese dwarf strain Norin 10B. S. 307 has superior rust resistance. The original stock of S. 227 received from Mexico segregated for resistance to brown rust and selections have been made for resistance. Seeds of S. 227 and S. 307 were multiplied at Wellington in the Nilgiri Hills during the summer of 1966 and these varieties are undergoing extensive yield tests.

Besides the selections made at the Indian Agricultural Research Institute, valuable selections were made at Ludhiana, Pant Nagar and Durgapura in the dwarf material sent to them. At Ludhiana, two selections PV. 18 and S. 227 have been found to do well. Selections for brown rust resistance have been made in S. 227 at Pant Nagar.

Crosses between the dwarf wheat material from Mexico and promising Indian varieties were made in 1963, and several of the hybrid derivatives hold great promise for a further improvement of the yield potential and quality of wheat. Through induced mutations the grain colour of Sonora 64 and Lerma Rojo have been changed from red to amber. The quality and quantity of protein in these varieties have also been considerably improved (Varughese, G. and Swaminathan, M. S. 1966. *Curr. Sci.* **35** (18) : 469-70).

Nearly 400,000 hectares were sown with dwarf wheat varieties during the *rabi* season of 1966. Arrangements have been made to supply fertilizers in adequate quantities for this area and it is expected that the cultivation of such non-lodging varieties in conjunction with suitable agronomic practices would help to double India's wheat production within the next five years.

GLOSSARY

Arhatyas	Wholesale grain dealers
Atta	Coarse wheat flour of 95–97 per cent extraction
Bakhar	Harrow
Baniya	Trader
Barani	Rainfed
Bhabar	Damp and low-lying areas
Bhangar	Old alluvium
Bhisti	Waterman
Bhusa	Straw
Birra	Mixed cropping of wheat and gram grown mixed in afield
Chakki	Flour-mill
Chapattee	Thin circular bread
Chhaj	Winnowing basket
Chokar	Wheat bran or bran
Dab	Water-stagnating area
Dabar	Low-lying area
Dalal	Middleman or broker
Dane	Discount
Dufan	Local seed drill
Garda	Discount
Gharat	Water-driven flour-mill
Guntaka	Blade harrow
Kabar	Rubbish
Kalai	Black gram (wild)
Kankar	Un-uniform, hard earthen bodies
Karail	Black clay soils
Karda	Discount
Kera method	Method of sowing wheat in irrigated areas
Khadar	Bank areas of a river (low-lying)
Kharif	Rainy season crop (June to Sept.-Oct.)
Khatti	Underground godown for grains
Khurpi	A small weeding implement (weeder)
Kiari	Small plot
Kohi	Rocky area
Kothas	Rooms, godowns
Krishi Pandit	Outstanding farmer
Kutcha	Muddy (made of earth; *cf. pukka* or made from lime and cement)
Kutcha arhatyas	Traders who directly purchase farm produces from farmers

Lakh	One hundred thousand (1,00,000)
Maida	Very finely sieved flour
Mandi	Wholesale grain market
Mar	Soil class in Bundelkhand area of M.P.
Maund	Old unit of weight. Equivalent to 37 kg. approximately
Meesala guntaka	Slit hoe
Munim	Cashier, accountant, *arhatya's* clerk
Murrum	Decomposed trap rock
Nari	Seed drill
Nari plough	Plough along with which a seed drill is attached
Palewa	Pre-sowing irrigation
Palla	A sack or rectangular piece of cloth in which grains are taken
Palledar	A man who handles goods (loads), market labourer
Paratha	Fried bread
Pata	Levelling plank
Phal	Plough blade
Pora method	Sowing method accomplished by a seed spout attachment to the country plough
Puri	Small circular bread fried in vegetable or pure *ghee*
Rabi	Winter crop (Oct. to Jan.-Feb.)
Rauni	Pre-sowing soaking
Rawa	Semolina
Regur	Black cotton soil
Rola	Labourer who skilfully cleans the wheat
Roti	Bread (*chapattee*)
Sathri	Coarse rice
Semya *Sewayya*	Thread-like preparation made of flour or *maida*
Sohaga	Levelling plank
Suji	Semolina
Suparah	Bullock-drawn buck scraper
Tarai	Submountainous or damp areas. Areas on the foot of hills
Thekka	Bamboo bag
Tifan	Local seed drill
Tola	Man who professionally weighs the farm produces in villages
Uppumav	Saltish preparation from semolina

INDEX

Aecidium berberidis, 215
Aegilops, 19, 48, 49, 80, 81
  bicornis, 48
  cylindrica, 44
  longissima, 50
  speltoides, 48, 49, 50, 53, 80, 89
  squarrosa, 45, 48, 49, 50, 80, 221
  triunicalis, 221
  umbellulata, 80, 89
  ventricosa, 221
Aegilotriticums, 81
aestivum wheats, 20, 38, 95, 111, 126
Agronomic practice, vernalization in, 197
Agronomy–cultural practices, 282–326
  costs of cultivation, 322–24
  mixed cropping with wheat, 298–301
  moisture requirements of wheat, 302–12
  weeds and their control in wheat crop, 312–22
  wheat in rotation, 294–98
Agronomy–manures and fertilizers, 258–81
  foliar application of fertilizers for increasing yield of wheat, 280–81
  manures and fertilizers in relation to soils, 278–80
  micronutrients, 278
  response to fertilizers, 258–77
Agropyron, 19
  elongatum, 81
  intermedium, 81
  longiaristatum, 221
  rust, 215
  semicostatum, 221
  tricophorum, 81
  triticeum, 48
Albumin, 161
Allopolyploid, 48
Alluvial soils of
  Bihar, 253–54
  Delhi State, 252–53
  Uttar Pradesh, 251–52
Alluvium
  of Bihar and Uttar Pradesh, 253–54, 278–79
  of the Punjab, 254, 279
  north of the Ganges, 253–54
  south of the Ganges, 254
Alternaria, 96, 122, 239
  diseases, 126, 239
Amino acid, 161
  composition of crude gluten, 165
  composition of wheat proteins, 165–66
Ammonium
  chloride, 262
  nitrate, 260, 261
  phosphate, response to, 272–73
  sulphate, response to, 258, 259, 260, 261
  sulphate-nitrate, response to, 262
Amphidiploids, 74
Anagallis arvensis, 313
Anatomy, 25–29
  of leaf, 27–29
  of root, 25
  of stem, 25–27
Aneuploid analysis, 53–54
Aneuploids, use of, 81
Angoumois grain moth, 249
Anguina tritici, 99, 100, 238, 239, 244, 246
Anthocyanin pigmentation, genetical studies on, 59
Aphids, of wheat, 100, 244, 245
Aphis maidis, 244, 245
Arabian *durum*, 112, 116
Archaeological evidence, of origin of wheat, 14–16
Area and production of wheat, 2–7, 8, 344–45
Arhatyas, 347, 348
Ash content, of wheat, 171–72
Asphodelus tenuifolius, 313, 321
Atta, 167
  loss of nicotinic acid in, 169–70
  thiamin content of, 167
Avena fatua, 221
Awn
  colour, genetical studies on, 58
  development, genetical studies on, 57
  promoter genes, 57
Awning, inheritance of, 57

β-amylase, 175
B genome
  origin of, 19
  source of, 48–49
Bakhar, 283, 315, 334, 335
Baking
  quality, 117–18, 175–78
  tests, 176, 177
Bar harrow, 315, 335
Barani, 118, 335
  conditions, 283
  crop, 282
Bathua, 313
Beetle, flour, 249
Benzene hexachloride, 246
Berberis, 211, 212, 215
  aristata, 215
  coriaria, 215
  lycium, 215, 223
  umbellata, 215
  vulgaris, 215, 223
Berseem, 259, 297
Bhangar, 252
BHC, 245, 250
Bhisti, 348
Bhusa, constituents of, 236, 327
Bihar
  alluvial soils of, 253–54, 278–79
  Gangetic alluvium of, 253–54, 279
  wheat breeding in, 122

Bihar Manurial Trials in cultivators' fields, 259
Biometrical studies, on yield, 117
Bipolaris
  bicolor, 237
  halodes, 237
  sorokiniana, 237
Birra, 298
Black rust, 96, 208, **209–10**
Black soil, 302, 307
  of Bombay, 255, 279
  of Madhya Pradesh, Bombay and Mysore, 279
  of Narmada Valley, 283
  regions of central and southern India, 254–56
Blissus leucopterus, 244
Bombay
  black soils of, 255, 279
  soils of, 255
  wheat breeding in, 125–26
Borer, stem, 246
Brachypodium sylvaticum, 221
Bran, 352
Brassica campestris, 297
Bread making, 176
Bread wheat, 8, 15, 39–40, 48 (*see* also *T. aestivum*)
Breeding (*see* also wheat breeding)
  cytogenetics in relation to wheat, 74–87
  problems and objectives of, 95-105
  for resistance to disease, 96–100, 110–15
  for resistance to drought and lodging, 96
  for resistance to smuts and bunts, 116, 225-26. 232
  for response to fertilization, 116
  rust-resistant wheat, for the hills, 115
  for special features, 117
  wheat in India, 89–95, 101-5
Briza minor, 221
Broadcasting, 334–35
Bromus
  carinatus, 221
  catharticus, 221
  coloratus, 221
  japonicus, 221
  mallis, 221
  patulus, 221
Brown rust, 96, 208, **210–11**
Buck scraper, bullock-drawn, 336
Bug, pale green, 100, 246
Bullock labour, productivity of, 323–24
Bullock-drawn buck scraper, 336
Bunt, 96, 116. 226–30
  breeding for resistance to, 116, 225–26, 232
  smuts and, 224–32

Calcium content, 172
Calcium cyanamide, 316
Cane sugar, 175
Carbon
  disulphide, 249
  tetrachloride, 249, 250
Carthamus oxyacantha, 313
Cephus cinctus, 244
Ceresan, 230
  New Improved, 230
Chakki, 167, 170
Chapattee-making, 176–78
  quality, 101, 117–18, 176–78
Chapattees, 10
Chatri, 313
Cheeks, 25
Chemical control, of weeds, 316–22
Chemicals
  for controlling weeds, 316–22
  inorganic compounds, 316
  organic compounds, 316–22
Chenopodium album, 313
Chhaj, 342
Chhoti dudhi, 313
Chinch bug, 244
Chlorophyll
  parenchyma, 26
  and viable mutation rates, 84
Chokar, 352
Chopin extensograph, 176
Chromosome
  of Chinese Spring, 53
  doubling in *Triticum* sp., 79
  identification of, 54
  morphology, 49–50
  number, 15
  pairing in polyhaploids, 50
  somatic, 51
  of *Triticum aestivum*, 54
Chrotogonus spp., 244, 245
Chutrimatri, 313
Classification, 33–34
  of agricultural varieties of wheat, 45–46
  of genus *Triticum*, 34
  of Indian wheats, 20
Club wheat, 15
Cockles, 100, 246
Coleoptile, 24
Collateral hosts, 216–21
Common wheat, 15
Cone wheat, 38–39
  Egyptian, 39
Conservation of soil moisture, 306–8
Control measures for
  bunt, 229–30
  grasshoppers, 245
  leaf blotch, 236
  leaf spot, 238
  loose smut, 225–26
  powdery mildew, 235
  rusts, 223
  termites, 245
  tundu disease, 239
  weeds, 314–22
Convolvulus arvensis, 313
Cooperative marketing, 352
Copper
  carbonate, 230, 232
  sulphate solution, 229, 316
Corynebacterium tritici, 99, 238
Costs of cultivation, 322–24
Country plough, 283, 292
Crease, 25
Crop rotation, effect of, 297
Crop sequences, effect of, 297
Cropping
  open system of mixed, 298

Cropping
  haveli system of mixed, 298, 335
  methods, for controlling weeds, 315–16
  mixed, 298–301
Crops, rotated with wheat, 297
Cultivated emmer, 36–37
Cultivated species, 33
Cultivation
  costs of, 322–24
  effect of frequency of, 284
  preparatory, 282–84
Cultural practices, 282–326
  influence of irrigation on, 311–12
Cynodon dactylon, 313
Cyperus
  niveus, 245
  rotundus, 245, 313
Cytogenetical studies, 48–54
Cytogenetics, in relation to wheat breeding, 74–85
Cytogenetics and genetics, 48–75

D genome, 49, 80
Dab, 315
Dabar, 252
Dalal, 348
Dane, 349
Day-length, in wheat-growing tracts, 195
DDT, 246, 250
Deccan trap, 254, 255
Dehiscence, 201
Delhi State
  cultivation in, 283
  Gangetic alluvium of, 252–53
Desert
  plants, 183
  soils, 256–57, 280
Desiccation resistance, 183
  tests, some variants of, 185–86
  tests on tissues, 185
  tests on whole plants, 185
Devernalization of seeds, 194–95
Diallel cross method, 119
Di-ammonium phosphate, 272
Diastatic
  activity, 174–75
  enzymes, 174, 175
Dicalcium phospate, 270
dicoccum wheat, 10, 74, 89, 95, 102, 111
  improvement of, 115
Dieldrin, 250
Dinkel
  genome, 49
  series, 34, 45
Diploid behaviour, of hexaploid wheat, 50–51
Disc harrow, 335
Disease resistance
  breeding for, 96, 110–115
  genetics of, 116
Diseases, 96–100, 208–43
  Helminthosporium, 237–38
  leaf blotch, 235–36
  other diseases, 238–39
  powdery mildew, 232–35
  rusts, 208–23
  smuts and bunts, 224–32
Distribution, of wheat, 302–3, 346, 348
DNC, 316
DNP, 316

Dough, 176
  testing, 175–76
Drechelera
  graminea, 237
  tritici repentis, 237
  tritici vulgaris, 237
Drills
  fertilizer-cum-grain, 336
  rabi, 336
  seed, 336
Drought
  breeding for resistance to, 96
  cell size in relation to, 186
  hardening to, 189–91
  resistance, 186
    work on, 188–91
Dubh, 313
Dufan, 293
Durum wheat, 10, 37–38, 74, 89, 95, 102, 111, 116, 126, 346
  improvement of, 115–16
Dwarf wheat, 8, 15 (*see* also *T. sphaerococcum*)
  Indian, 43
  varieties, developing, 354
Dwarfism, genetical studies on, 59

Ear, 24, 197, 198, 201
Ear cockle, 239
Earthing up, 293
Eelworm, 239
Egyptian cone wheat, 39
Einkorn, 15, 45
  series, 16, 34
  spelt, 35
Ellerton's hypothesis, 20
Elymus, 19
  hybrids with *Haynaldia* and, 81
Embryo, 25
  culture, use of, 81
  development of, 33
Embryology, 29–33
Emmer
  cultivated, 36–37
  genomes, 49
  series, 34
  wheat (*see T. dicoccum*)
  wild, 15, 35–36
Endosperm, 25, 162
  proteins of, 166
Endothecium, 30
Enzymes
  diastatic, 174, 175
  in flour, 173–75
  phytase, 175
  proteolytic, 175
Epidermis
  of leaf, 27
  of root, 25
  of stem, 26
Erysiphe graminis tritici, 96, 232, 235
Ethylene
  dibromide, 249, 250
  dichloride, 249, 250
Ethylmercury
  chloride, 230
  phosphate, 230
Euphorbia dracunculoides, 313
Eurygaster maura, 244, 246
Evapo-transpiration, 304

Exotic wheats, introduction of, 106
Exports, of wheat, 346
Extensograph, 176

Fallowing, 307
Farinograph, 176
Farmyard manure, 259
  response to, 264–66
Fat, 170
Fermentograph, 176
Fertilization, 30
  breeding for response to, 116
Fertilizer(s)
  breeding for response to, 116
  effect on milling composition, 172
  effect on thiamin of, 168
  foliar application of, 280–81
  and manures, 258–81
  mixed nitrogen and phosphate, 274–75
  nitrogenous, 258–64
  phosphatic, 268–72
  in relation to soils, 278–81
  response to, 258–77, 354
  treatments, 172
Festuca
  gigantea, 221
  kashmiriana, 221
Field capacity, 190
Flag smut, 96, **231–32**
Float plane, 336
Floret, morphology of, 24
Flour
  beetle, 249
  composition of, 174
  enzymes in, 173–75
Foliar application of fertilizers, 280–81
Foot-rot disease, 99, 237
Forma specialis, 221
Formalin, 230
Forms, 45
Fumaria parviflora, 313
Fumigants, 249–50
Fumigation, 250
  of grain, 249
Fundamental parenchyma, 26
Fungicides, 229–30
  seed-dressing, 231, 232
Fusarium, 237

Gajra, 313
Galls, 100, 239, 246
Gamma BHC, 250
Gangetic alluvium of
  Bihar, 253–54, 258, 279
  Delhi State, 252–53
  U.P. and Bihar, 251–54, 278–79
Garda, 349
Gene-centre, 19
Genes
  awn promoter, 57
  on different chromosomes, 50, 53, 54
  dwarfing, 354
  epistatic, 57
  Norin dwarfing, 354–56
Genetic (s)
  control, of hexaploid wheat, 50–53
  and cytogenetics, 48–75
  of disease resistance, 116
  transfer of characters, 79
Genetical studies, 57–70
Genome
  A, 49
  AAB, 49
  AB, 49
  analysis and origin, 48–49
  approach, 74
  B, 19, 48–49
  concept, 76
  D, 49, 80
  Dinkel, 49
  emmer, 49
  G, 49
  symbol, 15
Genomic formulae, 20, 49
Germination, 193
Gharat, 167
Gliadin, 161, 164
Globulin, 161
Gluco-fructosans, 170
Glume, 24
  beak, 59
  blotch, 236
  colour, 58
  hairiness, 58
  shoulder, 59–60
Glutelin, 161
Gluten, 164–65
  content, 175
Glutenin, 161
Glycine max, 298
Grades of wheat, 351
Grain(s)
  colour, genetical studies on, 58–59
  development, 202
  morphology of, 25
  number, 193
  protein, 164
  quality, 100–1, 161–82
Grain borer, 246
Grain quality, 100–101, 161–82
  baking and *chapattee*-making quality, 175–78
  effect of milling, 172–73
  enzymes in flour, 173–75
  fat, 170
  mineral matter, 171–72
  phytic acid, 170–71
  proteins in wheat, 161–66
  sugars, 170
  vitamins, 167–70
  wheat blends and substitutes, 178–79
Grain weevil, 246
Grasshopper, 100, 244, 245
Green-manuring, 259, 265
  effect on nicotinic acid of, 169
Growth
  factor, 70
  habit, 192
  and nutrition, 197–203
Guar, 298
Guntaka, 334

Hand pulling, of weeds, 314–15
Hand tools, for harvesting, 341
Harmolita grandis, 244
Harrow-bladed hoe, 335
Harrows, 294, 335–36

Harvesting, 341–42
    and threshing, 293–94
Hatching factors, 246
Haveli system, of sowing, 298, 335
Haynaldia, 19
    hybrids with *Elymus* and, 81
Heading stage, 304
Helminthosporium, 96, 99, 122
    bicolor, 237
    diseases, 237–38
    gramineum, 237
    halodes var. *tritici*, 237
    nodulosum var. *tritici*, 237
    nomenclature of, 237
    sativum, 237, 238
    tritici, 237
    tritici-repentis, 237, 238
    tritici vulgaris, 237
Helmisporium, 237
Herbicides, 321
Hessian fly, 244
Hexachlorobenzene, 230
Hexaploid wheat
    genetic control of, 50–53
    nomenclature of, 20–23
Hilari jamesii, 221
Hill bunt, 116
Hill soils, of the Siwaliks and the Himalayas, 256, 280
Hill wheat, 10
Hilly regions, of the Himalayas and the Siwaliks, 256
Himalayas, soils of hill regions of, 256, 280
Hiran khuri. 313
History, and origin of wheat, 14–16
Hoe
    harrow-bladed, 335
    slit, 335
Hoeing, 314–15
Homoeologous groups, 54
Hordeum, 19, 80
    distichum, 221
    murinum, 221
    stenostachys, 36, 221
Hoshangabad winnower, 294
Hot-water treatment, for loose smut, 225
Human labour, productivity of, 323–24
Humidity, influence on infection by bunt spore, 229
Hybridization
    intergeneric, 79–80
    technique of, 89, 106–9
Hybrids
    with *Haynalida* and *Elymus*, 81
    Wheat-*Aegilops*, 80–81
    Wheat-*Agropyron*, 81
    Wheat-rye, 80
Hydrocyanic acid gas, 249

Implements and machinery, 328–43
    harvesting and threshing, 341–43
    intercultivation, 335–41
    seed-bed preparation, 333–34
    sowing, 334–35
    tillage operations with indigenous implements, 328–33
Imports of wheat, 1, 345
Indian Agricultural Research Institute
    irrigation experiments at, 310–11
    varieties evolved at, 132–37
    wheat breeding at, 109–20
    work on drought resistance at, 188–91
Indigenous implements, tillage operations with, 328–33
Indigenous plough, 328–33
Indo-U.S. Project on Soil Fertility and Fertilizer Use, 258, 259, 273, 276
Indus alluvium, of Punjab, 254, 259, 279
Inflorescence, morphology of, 24
Inheritance
    of field resistance to rust, 60–63
    of seedling resistance to individual races, 63–69
Inhibitors, 70
Intercultivation, 293, 335–41
Interculture, for controlling weeds, 315
Intergeneric
    crosses, 89
    hybridization, 79–81
Introduction, of exotic wheat, 106
Irrigation, for wheat cultivation, 10, 308–12
Irrigation experiments
    at I.A.R.I., 310–11
    in Punjab, 308–9
    in relation to manuring, 311
    in U.P., 309-10
Isopyron fumarioides, 210

Jointing stage, 304
Jumna *khadar*, 252
Jungli gobhi, 313

Kabar, 259
Kainite, 316
Kalai, 298
Kankar, 251, 255, 257
Karail, 251, 255
Karda, 349
Karnal bunt, 96, 116, **230–31**
Karyotypes, 49
Kera method, of sowing, 312, 335
Kerl soil, 282
Kernel
    carbonized, 15
    composition of, 172, 173
    of dwarf wheat, 15
Khadar, 252, 253
Khamri, 178
Khapra, 246, 249
Khattis, 351
Khorasan wheat, 37
Khurpi, 314, 315
Kiari, 309
Kohi, 252
Kothas, 351
Krishan nil, 313
Krishi Sangraha, 333
Kulcha, 178

Lake Dwellers' Wheat, 23, 48
Land levelling, and smoothing, 336–41
Large spelt, 43–44
Lathyrus aphaca, 313
Launaea aspleniifolia, 313

Leaf
  anatomy of, 25–29
  epidermis of, 27
  parenchyma, 27
  sclerenchyma, 27–29
  vascular bundles, 29
Leaf blotch, **235–36**
Leaf-blotching, genetical studies on, 59
Leaf rust, 96, 208, 210–11
  resistance, 80, 89
Leaf spot diseases, 96, 237, 238
Leaves, morphology of, 24
Lemma, 24
Levelling plank, 334
Light, influence on wheat, 191–93
Linguistic evidence, of origin of wheat, 14
Lipid, 164
Listing, 282
Loaf volume, 173
Lodging, 203–4
  breeding for resistance to, 96
Lolium perenne, 221
Loose smut, 96, 112, **224–26**
  control of, 225–26
  hot-water treatment for, 225
  solar heat treatment for, 225
Lysine, 166

Macaroni wheat, 8, 15, 37–38 (*see* also *T. durum*)
Machinery and implements, 328–43
Madhya Pradesh
  black soils of, 279
  wheat breeding in, 122–25
Maina, 313
Makha wheat, 15, 44
Maltose, 175
Maltose figure, 175
Malva parviflora, 313
Manures and fertilizers, 258–81
  irrigation in relation to, 311
  in relation to soils, 278–80
  response to organic, 264–68
Manurial trials, results of, 267
Manuring, irrigation in relation to, 311
Mar, 255
Market charges, 348–49
Marketable surplus, of wheat, 346–47
Marketing, 344–53
Matri, 313
MCPA, 321, 322
MCPB, 322
Mechanical methods, for controlling weeds, 314–15
Medicago denticulata, 313
Meesala guntaka, 335
Megagametophytes, 30
Megaspores, 30
Megasporogenesis, 30
Mehar system, of threshing, 342
Melilotus
  alba, 313
  parviflora, 313
Methyl bromide, 249
Micronutrients, 278
  foliar application of, 280
Microspore, 30
Microsporogenesis, 29–30
Microtermes obesi, 100, 244
Mill streams, analysis of, 162
Milling
  effect of, 172–73
  qualities, 117–18
Mineral matter, 161, 171–72
Mixed cropping, with wheat, 298–301
Mohenjo-Daro, 15, 16
Moisture (*see* also soil moisture)
  relations, 183–91
  requirements of wheat, 302–12
Molya disease, 239
Mono-ammonium phosphate, 272
Monosomic analysis, 54, 57, 69
Morphological characters, 186–87
Morphology
  chromosome, 49–50
  of grains, 25
  of inflorescence, 24
  of leaves, 24
  of roots, 23
  of stem, 23–24
  and systematics, 19–47
Motha, 313
Multivalent suppressor gene, 50
Murrum, 255
Mutations
  induction and use of, 81–84
  rate, 83
  types of, 83
Mysore, black soils of, 256, 279

Nari, 293
  plough, 292, 335
Narmada Valley
  cultivation in, 283
  soils of, 256
Nematode
  galls, 239
  pests, 244, 246
Neolithic Dolmen period, 15
Neovossia indica, 96, 116, 230–31 (*see* also Karnal bunt)
Niacinogen, 169
Nick, 117
Nicotinic acid, 168–70
Nitric acid, 316
Nitrogen, 258–64
  content of plant, 198–200
  response to application of, 258–64
  response to different levels of, 264
  response to different sources of, 263
  response to phosphorus and, 274
  time of application of, 265
  varietal differences in uptake of, 200
Nitrogenous fertilizers, 260–63
  combined phosphatic and, 272–75
  time of application of, 263–64
Nitrophos, response to, 273
Nitrophosphate, 273–74
Nomenclature
  of hexaploid wheats, 20–23
  taxonomy and, 19–23
Norin dwarf genes, 354–56
Nulli-haploid, 50
Nutrient status of soil, 303
Nutrition and growth, 197–203

Odontotermes obesus, 100, 244
Olpad thresher, 342
  bullock-drawn, 294

- Organic compounds, for control of weeds, 316–22
- Organic manures, response to, 264–68
- Origin
  - and history, 14–16
  - of polyploid wheat, 48
  - of tetraploid wheat, 48–49
- Osmotic concentration, investigations on, 184–85
- Osmotic pressure, 184
- Oudh plough, 315

- Pale green bug, 100, 244, 246
- Palea, 24
- *Palewa*, 312
- *Palla*, 294, 342
- *Palla* system of threshing, 294, 342
- *Palledar*, 348
- *Paratha*, 178
- Parenchyma
  - chlorophyll, 26
  - fundamental, 26
  - leaf, 27
- Partial bunt, 230–31 (*see* also Karnal bunt)
- *Pata*, 336
- *Patela*, 334, 336
- Pedigree seed, 105
- Pentaploid hybrids, in wheat breeding, 74–79
- Pericycle, of root, 25
- Persian wheat, 15
- Pests, 100, 244–250
- *Phal*. 315
- *Phalaris minor*, 221
- *Phaseolus*
  - *mungo*, 298
  - *radiatus*, 298
- Phenoxy acids, 321–22
- Phosphate, response to, 274, 275
- Phosphatic fertilizers
  - combined nitrogenous and, 272–75
  - experiments with, 268–72
  - influence on thiamin content of, 168
  - placement of, 272
- Phosphorus, 200
  - responses to, 268–72
- Photo-inductive treatment, 196
- Photo quantum, 197
- Photoperiod, 193, 196
- Photosynthesis, contribution to grain yield from, 201
- Photothermic quanta, 196–97
- Physiologic races
  - of black rust, 209
  - of brown rust, 210–11
  - of loose smut, 224–25
  - of rusts, 221–23
  - of stinking smut, 229
- Physiology, 183–207
  - growth and nutrition, 197–203
  - influence of light and temperature on wheat, 191–93
  - lodging, 203–4
  - moisture relations, 183–91
  - vernalization, 194–97
- Phytase, 175
- Phytic acid, 170–71, 175
- Phytin, 170, 172
- Phytin phosphorus, 171
- *Phytophaga destructor*, 244
- *Piazi*, 313
- *Pitpapra*, 313
- Plank, levelling, 334
- Plough
  - country, 292
  - indigenous, 328–33
  - *nari*, 292, 335
- Ploughing, 282
  - hot weather, 283
  - summer, 333
- *Poa nemoralis*, 221
- *Pohli*, 313
- Polish wheat, 15, 38
- Pollen grains, 30
- Polyhaploids, chromosome pairing in, 50
- Polyploid series, 48
- *Pora* method, of sowing, 335
- Potash, response to, 276, 277
- Potassic fertilizers, field experiments with, 275–77
- Potassium
  - content of plant, 200
  - iodide, 225
- Powdery mildew, 96, **232–35**
- Preparatory cultivation, 282–84
- Prices, 349–50
- Production, 344–45
  - of wheat in world, 1, 2–7
- Productivity, human and bullock labour, 323–24
- Products, of wheat, 352
- Prolamin, 161
- Prophylls, 24
- Protein(s)
  - biological values of, 161
  - in wheat, 161–66
- Proteolysis, 175
- Proteolytic enzymes, 175
- Proteose, 161
- Protoplasmic viscocity, investigations on, 184–85
- *Puccinia*
  - *glumarum*, 96, 208, 211, 216, 221, 229
  - *graminis*, 221
  - *graminis agropyri*, 215
  - *graminis avenae*, 221
  - *graminis* var. *tritici*, 45, 221
  - *graminis tritici*, 96, 208–10, 221, 222
  - *persistens*, 215
  - *recondita*, 45, 96, 208, 210
  - *rubigovera*, 216
- Punjab
  - cultivation in, 283
  - Indus alluvium of, 254, 259, 279
  - irrigation experiments in, 308–9
  - soils of hill regions of, 256
  - wheat breeding in, 118–21
- Pure-line selection, 105–6
- *Puri*, 178
- Pyrethrin, 250
- *Pythium*, 237

- Quality score, 177
- *Rabi*
  - drills, 336
  - weeds, 321

Race, 33
Rachis, anthocyanin pigmentation of, 59
Rainfall
  and distribution of wheat, 302–3
  in wheat-growing areas, 302
Rajasthan
  desert soils in, 256–57
  wheat breeding in, 121
Rauni, 309, 312
Rava, 10
Reaper (s)
  binders, 341–42
  bullock-drawn, 341
Regur, 254, 255
Resistance
  indices, 188, 189
  to wilting, 189
Rhizopertha dominica, 246, 249
Riboflavin, 168
Rivet wheat, 15, 38–39
Rola, 348
Roller, 334
Root rot, 237
Roots
  adventitious, 23, 25
  anatomy of, 25
  epidermis of, 25
  morphology of, 23
  primary, 23, 25
  variation in growth of, 187
Rotation, wheat in, 294–98
Roti, 178
Rust(s), 96, 99–100, 111–15, 208–23
  breeding varieties resistant to, 89
  collateral hosts of, 216–21
  control measures for, 223
  inheritance of field resistance to, 60–63, 63–69
  mode of perpetuation of, 211–16
  physiologic specialization in, 221–23
  resistance to, 69, 70
Rust-resistant wheat, breeding of, 111–115

Sailaba, 303
Sclerenchyma, of leaf, 29–30
Scutellum, 24
Scythe, 341
Season, wheat growing, 90
Secale, 19
Seed
  certification, 225
  dressing, 229–30
  drills, 336
  quality, 293
  rate, 288–92
  vernalized, 197
Seed-bed preparation, 333–34
Seed-germination test, 187
Seedling
  blight, 237
  drought hardiness, 187
Seedling resistance
  inheritance of, 63–69
  pure-line selection for, 105–6
Selection, pure-line, 105–6
Semolina, 10, 352
Semya, 10
Senji, 313
Septoria
  graminum, 235
  nodorum, 236
  tritici, 235, 236
Sesamia inferens, 244, 246 (*see* stem borer)
Share, 328
Shoe, 328
Sickle, 341
Sinapsis arvensis, 316
Singh Patela, 336
Silophilus oryzae, 246, 249
Sitotroga cerealella, 249
Siwaliks, soils of hilly regions of, 256, 280
Slit hoe, 335
Small spelt, 35 (*see* also *T. monococcum*)
Smuts, 100
  breeding for resistance to, 116
  and bunts, 224–32
Sodium
  chloride, 316
  nitrate, 316
  thiosulphate, 235
Soft wheat, 15
Sohaga, 309, 334
Soil(s)
  drought, index of resistance to, 188
  of the Himalayas and Siwaliks, 256, 280
  manures and fertilizers in relation to, 278–80
  moisture
    conservation of, 306–08
    studies, 305
    variation in, 190
  of Narmada Valley, 256
  nutrient status of, 303
  in relation to plant development, 303–4
  in relation to wheat, 251–57, 302–3
  temperature, influence on infection by bunt spore, 229
  types, response of wheat to potash on various, 277
  of wheat-growing areas, 251–57
Soil Fertility and Fertilizer Use, Indo-U.S. Project on, 258, 259, 273, 276
Solar
  energy, 249
  heat treatment, for loose smut, 225
Sorts, 90, 95
Sowing, 334–35, 336
  date, 193
  methods of, 292–93, 312
  season, 333
  shallow, 230
  time of, 284–88
Soybean, 298
Spacing, 292
Species, of wheat, 34–35, 90–95
Speckled leaf blotch, 235
Spelt, 15
  large, 43–44
  small, 35
  wheat, 43
  wild small, 34–35 (*see* also *T. aegilopoides*)
Spergon, 225
Spergula arvensis, 313
Spike density, genetical studies on, 59
Spikelets, morphology of, 24
Sporads, 30

Sporogenous cells, 29
Spring vs. winter habit, genetical studies on, 59
Spring wheat, 8, 10, 192
Square head, 15
Starch, 173, 174
Stem
  anatomy of, 25–27
  epidermis of, 26
  mechanical tissue of, 26
  morphology of, 23–24
  parenchyma, 26
  vascular bundles of, 26–27
Stem borer, 100, 244, 246
Stem fly of wheat, 244
Stem rust, 96, 208, 209–10
  resistance, 89
Stinking smuts, 96, 116, 226–30 (*see* also
Stomata, 27, 186
  bunt)
Storage, of wheat, 249–50, 351–52
Storage pest, 246, 250
Straw, of wheat, 327
Straw worm of wheat, 244
Streak-mosaic resistance, 89
Stripe rust, 96, 208, 211
Sugars, 170, 176–77
Suji, 10, 352
Sulphur dust, 235
Sulphuric acid, 316
Summer ploughing, 333
Sunnhemp, 259
Suparah, 336
Superphosphate, 259
  response to, 268, 270, 273
Symptoms of
  flag smut, 231
  Karnal bunt, 230
  leaf blotch, 235–36
  powdery mildew, 235
  stinking smut, 229
  tundu disease, 238–39
Systematics and morphology, 19–47
  anatomy, 25–29
  classification, 33–34
    of agricultural varieties, 45–46
  description of wheat species, 34–45
  embryology, 29–33
  morphology, 23–25
  taxonomy and nomenclature, 19–23

Tapetum, 30
Tapioca flour, 179
Taxonomy and nomenclature, 19–23
Temperature, influence on wheat, 191–93
Termites, 100, 244–45
Terraced fields, 10
Tetraploid wheats, origin of, 48–49
Thalictrum, 210, 211, 212, 215
  javanicum, 215
Thekkas, 351
Thermic quantum, 197
Thiamin, 167–68
  distribution of, 172
  losses, 178
Threshing, 342
  and harvesting, 293–94
Tifan, 293
Tillage, for controlling weeds, 315
Tillage operations
  with indigenous implements, 328–33
  secondary preparatory, 335–36
Tillering, 303–4
Tillers, 23
  per plant, 304
Tilletia, 116
  caries, 96, 226, 229
  controversa, 226
  foetida, 96, 226, 229
Tola, 348
Toria, 297
Toxoptera graminum, 244, 245
Transpiration
  march of, 304–5
  ratio, 306
Transplantation, use of, 81
Tribolium, 249
  castaneum, 248, 249, 250
Triple superphosphate, 269, 274
Triploid hybrids, in wheat breeding, 74–79
Triticale, 80
Triticeae, 19
Triticineae, 19
Triticum, 19
  abyssinicum, 74
  aegilopoides, 15, **34–35**, 49
  aestivum, 1, 8, 15, 20, 23, 30, 33, 34, **39–40**, 48, 49, 50, 54, 57, 58, 59, 63, 69, 80, 89, 90, 125, 184, 346
  aethiopicum, 74
  ararticum, 34
  armeniacum, 33–34, 49
  bocoticum, 15, 34
  carthlicum, 34
  chromosome doubling in, 79
  classification of genus, 34
  compactum, 15, 20, 33, **40**, 43, 184
  dicoccoides, 15, 24, 34, **35–36**, 48, 49
  dicoccum, 8, 15, 24, 34, **36–37**, 48, 84, 90, 125, 184, 346
  durum, 8, 15, 33, 34, **37–38**, 58, 63, 69, 90, 125, 184, 346
  hybernum, 34
  macha, 15, 20, 34, **44**, 50
  monococcum, 15, 20, 24, 34, **35**, 44, 45, 48, 49, 50, 84, 184
  orientale, 34, **37**
  osmotic pressure and bound water content of, 184
  paleocolchicum, 34
  persicum, 15, 34, 37, 48
  percivalli, 34
  polonicum, 15, 34, **38**, 184
  pyramidale, 33, **39**
  spelta, 15, 20, 23, 24, 34, **43–44**, 80, 184
  sphaerococcum, 8, 15, 20, **43**, 58, 59, 90
  thaoudar, 34, 49
  timopheevi, 15, 34, **39**, 44, 45, 49, 79, 89, 106
  turgidum, 15, 34, **38–39**, 184, 225
  urartu, 34
  vavilovi, 20, 58, 59
  volgense, 34
  vulgare, 20, 34, 43, 90
  vulgare speltiforme, 23
  zhukovskyi, 15, 20, 34, **44–45**, 49
Trogoderma, 249, 250
  granarium, 246

Tundu disease, 99, **238–39**
Type, 45

Urea, 261
  spraying, 280, 281
Urocystis tritici, 96, 224, 231, 232
Ustilago nuda, 96, 224–26
Uttar Pradesh
  Gangetic alluvium of, 251–52, 278–79
  hill soils of, 256
  irrigation experiments in, 309–10
  wheat breeding in, 121–22

Varieties
  A 49, 122
  A 112, 122
  A 113, 122, 140
  A 115, 122, 140, 178
  Ao. 13, 106, 122, 140
  Ao. 68, 140, 178
  Ao. 85, 122, 140
  Ao. 88, 122, 140
  Ao. 90, 106, 122, 140
  Arabian *durum*, 116
  Arnej, 126, 139,
  B.R. 319, 122, 141
  Baart, 184, 185
  Bansi, 95, 346
  Bansi 103, 58
  Bansi 168, 138 (*see Motia*)
  Bansi 202, 138
  Bansi 224, 126, 138
  Bansipalli 808, 102, 138
  Baxi 228-18, 116, 126
  Bena, 106
  Bowie-Texas 3708-2, 111
  Bowie-Texas 7265-5, 111
  Brevor, 116
  C. 13, 106, 121, 139, **157–58**
  C. 46, 139
  C. 54, 140
  C. 217, 121, 137, **155**
  C. 228, 118, 137, **155**
  C. 250, 121, 137, **152–55**
  C. 253, 121, 137, **152**
  C. 273, 121, 137, **152**
  C. 281, 118, 138, **152**
  C. 285, 121, 138, **152**
  C. 286, 121, 138, **151**
  C. 518, 118, 137, **151**
  C. 591, 118, 137, **151,** 178
  Carsten's V, 111
  Ceres Klein, 111
  Chandausi, 95
  Chinese Spring, 53
  Cometa Klein, 111
  Dara, 95, 346
  Dawat khani, 95
  Democrat, 111, 112
  Dudia, 95
  Ekdania 69, 116, 125, 141
  Federation, 106
  Frondoso, 111
  Frontiera, 111, 117
  Gabo, 106, 111
  Gaines, 354
  Ganjagally, 95, 122
  Gaza, 111, 116
  Gulab, 116, 126, 138, 178

Varieties
  Hard Red Calcutta, 95
  Haura, 95, 105
  Hope, 53, 79, 184, 185
  Hussar, 116
  Hy. 5, 125, 141
  Hy. 8, 125
  Hy. 11, 125, 140, **155**
  Hy. 12, 125, 141
  Hy. 25, 125
  Hy. 38, 125, 141, **155**
  Hy. 65, 125, 141, **156**
  Hy. 277, 125, 141, **156**
  Hy. 278, 125, 140
  Jalalia, 95, 346
  Jamali, 95
  Jay, 126, 138, **156**
  Jaya, 102
  K. 13, 139
  K. 46, 139
  K. 53, 121
  K. 54, 121, 140
  Karachi Choice White, 95
  Kathia, 95, 116, 346
  Kenphad 25, 126, 138, **157**
    early No. 28, 126, 138
    red mid-late No. 39, 139
  Kenya 184. P.2.A.I.F., 111
  Kenya 388, 111
  Kenya 48 F (L.1), 111, 126
  Kenya E. 220, 111, 112
  Kenya Ploughman 318.0.3.B.2, 111
  Khandwa, 95, 346
  Khapli, 95, 111, 125, 346
  Kharchia, 102
  Kononso, 115
  Kubanka, 111
  La Prevision, 112
  Lal kanak, 95, 346
  Lal kusurwala, 122
  Lal pissi, 95, 346
  Lalka, 95
  Lerma Rojo, 13, 116, 354, **355–56**
  Malvi, 95
    local, 116
  Marquillo, 86
  Marquis, 184
  Mayo 64, 354
  Mediterranean, 111
  Mindum, 111
  Motia, 116, 126, 138
  Mundia, 109
  N. 133, 126, 139
  N. 177, 126, 139, **157**
  N. 179, 126, 139
  N. 345, 126, 139, **157**
  Niphad-4, 110, 126, 138, **156–57,** 178
  Niphad-81, 138
  N.P. 4, 105, 109, 110, 121, 122, 132, **141–42**
  N.P. 6, 105, 109, 110
  N.P. 12, 105, 109, 121, 122, 133, 204
  N.P. 52, 110, 122, 133, **142**, 204
  N.P. 54, 110
  N.P. 80–5, 110, 133
  N.P. 101, 133
  N.P. 111, 110, 133
  N.P. 114, 110, 112, 116, 133
  N.P. 120, 110, 133

Varieties
  N.P. 125, 110, 133, **142**
  N.P. 165, 110, 116, 133, **142–45**, 204
  N.P. 200, 137, **148**
  N.P. 700 series, 110, 111, 116
  N.P. 710, 112, 122, 133, **145**, 204
  N.P. 715, 133
  N.P. 718, 112, 121, 122, 133, **145**
  N.P. 720, 112, 134
  N.P. 721, 134
  N.P. 728, 134
  N.P. 737, 112, 134
  N.P. 745, 134
  N.P. 755, 134
  N.P. 758, 112, 122, 134
  N.P. 760, 112, 134
  N.P. 761, 112, 122, 128, 134, **145–46**
  N.P. 770, 115, 134, **146**
  N.P. 771, 134
  N.P. 775, 110, 112, 134
  N.P. 781, 134
  N.P. 783, 112
  N.P. 784, 112
  N.P. 785, 112
  N.P. 786, 112
  N.P. 789, 112 135
  N.P. 790, 112, 135
  N.P. 792, 112, 115, 135, **146**
  N.P. 797, 112, 135, **146**
  N.P. 798, 112, 122, 135, **146–47**
  N.P. 799, 112, 122, 135, **147**
  N.P. 800 series, 110, 111, 116
  N.P. 801, 135
  N.P. 802, 135
  N.P. 809, 112, 115, 135, **147**
  N.P. 822, 135
  N.P. 823, 116, 136, **147**
  N.P. 824, 116, 136, **148**
  N.P. 825, 115, 116, 136
  N.P. 826, 115, 136
  N.P. 827, 115, 136
  N.P. 828, 115, 116, 136
  N.P. 829, 115, 136, **148**
  N.P. 830, 116, 136
  Norin 10B, 356
  PV. 18, 356
  Padova, 106, 140
  Pakwani, 95
  Pb. 8A, 137
  Pb. 9D, 137
  Pb.C. 281, 110
  Pb.C. 518, 112, 204
  Pb.C. 591, 121
  Pissi, 346
  Pivla, 95
  Popatia, 95
  Potia, 95
  Puglu, 109
  Puora, 109
  Puseas, 109
  P.W. 3, 139
  P.W. 5, 139
  P.W. 12, 139
  R.S. 31-1, 121, 141, **158**
  Ridley, 106, 115, 135, **148–51**
  Rio Negro, 112, 117
  S. 227, 356
  S. 307, 356
  Samba, 95
Varieties
  Saphed pissi, 95
  Sharbati, 95, 346
  Sonora 63, 116
  Sonora 64, 116, 13, 354, **355–56**
  Spalding's Prolific, 111, 112
  Sukharai pissi, 122
  Thatcher, 53
  Timstein, 53
  Timstein derivative, 106
  Tremez Molle, 111
  Vijay, 126, 138, **156**
Varieties
  classification of agricultural, 45–46
  of wheat, 90–95, 132–58, 346
Vascular bundles
  of leaf, 29
  of stem, 26–27
Vegetative period, 196
Vermicelli, 10
Vernalization, 194–97
  in agronomic practice, 197
  quanta, 196–97
Vicia
  hirsuta, 313
  sativa, 313
Vitamin(s), 161, 167–70
  losses in, 178
Volume expansion, 282
Vulpia myuros, 221

Water-absorption capacity, 177
Water consumption, by wheat, 304
Water content, bound, 184–85
Water requirement, 188, 305–6
  computation of, 306
Waxy bloom, genetical studies on, 59
Weed control, methods of, 314–22
Weed-wheat competition, nature of, 314
Weeding, hand, 314
Weeds, 312–22
Weevil, 246
West Bengal, wheat breeding in, 122
Wheat
  acre yield, 13
  adaptability, 192
  aestivum, *see aestivum* wheat
  agricultural varieties, 45–46
  amino acid composition of proteins of, 165–66
  aphid, 100, 244, 245
  archaeological evidence of origin of, 14–16
  area and production, 2-7, 8, 344–45
  baking qualities of, 117–18, 175–78
  blends and substitutes, 178–79
  bran, 352
  bread, 8, 39–40 (*see* also bread wheat)
  chapattee-making qualities of, 101, 117–18 176–78
  classification of agricultural varieties of, 45–46
  commercial description of, 346
  compactum, 20
  cone, 38–39
  consumption, per capita, 346
  diastatic activity of, 174–75
  dicoccum (*see dicoccum* wheat)
  diseases of, 208–43
  distribution of, 302–3, 346, 348

- Wheat
  - duration of, 10
  - *durum*, 37–38 (*see durum* wheat)
  - dwarf, 8
  - Egyptian cone, 39
  - emmer, 8 (*see* also *T. dicoccum*)
  - English, 195
  - exotic, introduction of, 106
  - exports of, 1, 346
  - flag smut of, 96, 231–32
  - foliar application of fertilizers to, 280–81
  - genome symbol of, 15
  - grades for, 351
  - grain development in, 202
  - growth habit of, 192
  - hexaploid, nomenclature of, 20–23
  - hill, 10
  - history of, 14–16
  - imports of, 1, 345
  - improvement
    - of *dicoccum*, 115
    - of *durum*, 115–16
  - in India, 1–13
  - Indian dwarf, 43
  - influence of light and temperature on, 191–93
  - interrelation of soil type, rainfall and distribution of, 302–3
  - irrigation for, 308–12
  - Karnal bunt of, 230–31
  - kernel, chemical composition of, 172, 173
  - Khorasan, 37
  - linguistic evidence of origin of, 14
  - loose smut of, 224–26
  - macaroni, 37–38
  - Makha, 15, 44
  - marketable surplus, 346–47
  - milling quality of, 117–18
  - mixed cropping with, 298–301
  - moisture requirements of, 302–12
  - nematode, 238
  - nomenclature of hexaploid, 20–23
  - origin and history of, 14–16
  - per capita consumption of, 346
  - Polish, 38
  - polyploid, origin of, 48
  - prices for, 349–50
  - production, 1, 2–7, 8, 344–45
  - products, 352
  - proteins in, 161–66
  - rate of water use by, 306
  - regions growing, 90–95
  - Rivet, 38–39
  - in rotation, 294–98
  - scientific research in, 13
  - soils in relation to, 251–57, 302–3
  - species, description of, 34–45, 90–95
  - spelta type, 23, 48
  - *sphaerococcum*, 20
  - spring, 8, 10, 192
  - storage of, 249–50, 351–52
  - straw, 327
  - structure of grain of, 173
  - tetraploids, origin of, 48–49
  - time of sowing, 10, 284–88
  - tundu disease of, 99, 238–39
  - varieties of, 90–95, 132–58, 346
- Wheat
  - vernalized, 197
  - water requirement of, 188, 305–6
  - weeds of, 312–22
  - winter, 10, 192, 193
- Wheat-*Aegilops* hybrids, 80–81
- Wheat-*Agropyron* hybrids, 81
- Wheat aphids, 100, 244, 245
- Wheat breeding, 74–85, 86–131 (*see* also breeding)
  - in Bihar, 122
  - in Bombay, 125–26
  - cytogenetics in relation to, 74–85
  - for disease resistance, 96, 110–15
  - at I.A.R.I. and the states, 109–26
  - in India, 89–95
  - in Madhya Pradesh, 122–25
  - Norin dwarf genes in, 354–56
  - problems and objectives of, 95–105
  - in Punjab, 118–21
  - in Rajasthan, 121
  - for resistant varieties, 89
  - special requirements for, 101–5
  - triploid and pentaploid hybrids in, 74–79
  - in Uttar Pradesh, 121–22
  - in West Bengal, 122
- Wheat cultivation, irrigation for, 308–12
- Wheat-growing regions, 90–95
  - day-length in, 195
  - soils of, 251–57
- Wheat-Rye hybrids, 80
- Wheat species, description of, 34–45, 90–95
- Wheat straw worm, 244
- Wheat varieties, 132–58
- White-ants, 100, 244
- Wild emmer, 35–36 (*see T. dicoccoides*)
- Wild small spelt, 34–35 (*see T. aegilogoides*)
- Wilting
  - coefficient, 190
  - resistance to, 189
- Winnower, Hoshangabad, 294
- Winnowing
  - basket, 342
  - fans, 342
  - machines, 342–43
  - and winnowers, 342–43
- Winter wheat. 8, 10, 192, 193
- Wheat proteins, amino acid composition of, 165–66

- Xerophytic features, 183

- Yeast, 176
- Yellow ear rot, 238–39 (*see* Tundu disease)
- Yellow rust, 96, 208, **211–23,** 355
- Yield
  - biometrical studies on, 117
  - physiological causes of varietal difference in, 200–3
- Yielding ability, and adaptability, 95–96

- 2, 4–dichlorophenoxyacetic acid, 321
- 2, 4–dichlorophenoxybutyric acid, 322
- 2, 4–dinitrophenol, 316
- 2–methyl, 1–4 chlorophenoxyacetic acid, 322
- 2–methyl–4–chlorophenoxybutyric acid, 322
- 3, 5–dinitro-o-cresol, 316

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